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Protection of Ground Water Resources from the Effects of Accidental Spills of Hydrocarbons and Other Hazardous Substances (Guidance Document)

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The purpose of this study is to prepare guidelines and technical documents that can be utilized by industry, Federal, State, and local governmental agencies to assist in eliminating or minimizing the efforts of spills of contaminants that might adversely affect underground water which supplies, or can reasonably be expected to supply, any public water system.

Finally, this report and guidance fulfill that mandate contained in the Safe Drinking Water Act, Section 1442(a)(6) requiring that the Administrator of the Environmental Protection Agency "...carry out a study of methods of preventing, detecting, and dealing with surface spills of contaminants which may degrade underground water sources for public water systems."

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GUIDANCE DOCUMENT

PROTECTION OF GROUND WATER RESOURCES FROM THE EFFECTS OF ACCIDENTAL SPILLS OF HYDROCARBONS AND OTHER HAZARDOUS SUBSTANCES

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SECTION 1

INTRODUCTION

Accidental land spills of liquid wastes, toxic fluids and hydrocarbons occur in every region of the U.S. from incidents such as tank car accidents, train derailments, pipeline ruptures, bulk and underground storage leaks and improper storage and handling of equipment. Regulations have been established to protect the Nation's air, streams, lakes and coastal waters from contamination. There are no similar regulations protecting ground water. Ground water contamination resulting from spills is a significant problem and has recently received attention from industry and Federal and state authorities.

The purpose of this document is to assist state, regional and industrial personnel by providing guidance on spill prevention and clean-up methods as they relate to ground water contamination. The document is divided into several sections, each with a specific purpose.

The following is a general description of each of these sections:

- Hydrogeological Information - This section describes ground water and those hydrogeological factors which are important for the assessment and evaluation of a spill.

- Spill Damage Assessment Techniques - The information in this section describes the basic state-of-the-art in sub-surface spill damage assessment.

- Land Spill Prevention and Control Techniques - This section describes several prevention and control techniques used to minimize ground water contamination.

- Bibliography - This section contains those references used in the preparation of this document and others for the reader's further specific investigation or knowledge in the areas of spill abatement and prevention.

- Appendices - The appendices contain details regarding the following areas:

  A - Description of U.S. Aquifer systems

B - State laws applicable to ground water contamination
C - State and Federal spill response telephone numbers
D - State geologist to call for specific hydrogeological information in each state.

To use this document effectively, the reader should be aware of the contents in a general way. A step-by-step suggested procedure for the use of this document follows:

- Determine what is spilled and the volume.
- Contact state, Federal offices (Appendix C).
- Determine state laws applicable (Appendix B).
- Determine the hydrogeological condition and damage assessment of the area in as much detail as possible (Section 2, 3 and Appendix A). Contact with the state geologist may be helpful (Appendix D).
- Develop plan for clean-up and abatement immediately after an assessment has been made (Section 4).
- If technical information is needed and is not contained in this document, consult with a hydrogeologist and refer to the bibliography (Section 6).
- Document and evaluate all actions taken until clean-up is completed.
- To prevent spills, refer to Section 5 and the bibliography for the technology that is most widely used.

SECTION 2

HYDROGEOLOGICAL INFORMATION

1. What is Ground Water?

The term ground water is normally defined as that part of the subsurface water which is in the zone of saturation. The geology of the stratum governs the occurrence and distribution of ground water; the supply of water to the ground is determined by the local hydrology; and the movement of the ground water can be understood by applying the principles of fluid mechanics. In many areas ground water provides the major drinking water supply, and more than half of the population of the United States obtains its drinking water from this source. A general distribution of ground-water reserves in the U.S. and general descriptions of the 24 ground-water provinces as developed by the U.S. Geological Survey are presented in Appendix A.

2. Ground Water Movement

Ground water is usually moving in the natural state, although there are certain unique situations where ground water is essentially static. The rate of flow is governed by the permeability of the aquifer and the hydraulic gradient within it. Measured rates of ground water movement vary markedly, from many feet per day to a few feet per year. Field tests have reported velocities of more than 100 ft/day; however, a normal range is from 0.5 ft/year to 5 ft/day. The natural flow can be modified to produce higher or lower velocities by the presence of pumping wells, drains, and steeper or shallower water table or piezometric slopes.

3. The Susceptibility of Aquifers to Contamination from Spills

Recharge to an aquifer may be natural or artificial. Precipitation is the ultimate source of water for the natural replenishment of ground water. The recharge takes place by percolation of precipitation and surface water through the sub-surface strata. Percolation starts by a gradual wetting of dry surface particles and continues by capillary forces. The last stage of percolation is saturated flow by gravity through openings in the subsurface strata.

Where a water table exists, the surface of the saturated zone is not protected by a relatively impermeable layer and recharge with contaminated water can be direct. Where artesian conditions exist, the surface of the saturated zone is protected by an impermeable layer and contaminated recharge is usually indirect. Generally, recharge to an artesian aquifer occurs in outcrop areas where water table conditions exist. Deeper, more extensive artesian aquifers do not always outcrop at the surface and, in these cases, recharging must occur through the relatively impermeable layer. Therefore, artesian aquifers are much less likely to be contaminated than water table aquifers.

Artificial recharge is accomplished by water spreading, recharge through pits or other excavations of moderate depth and recharge through wells and shafts. Each of these may give a contaminant a direct route to an aquifer.

Another way that artificial recharge can occur is by the infiltration of water from a surface water body. Normally, the aquifer will flow into the surface water. However, if excessive pumping from the aquifer creates a cone of depression near the surface water, contaminated surface water can backflow into the aquifer. Salt water intrusion into coastal aquifers is an example of this.

Aquifers may also be contaminated by inter-aquifer migration of ground water. This fact should be considered when evaluating the potential damage that could happen as a result of a spill.

4. Ground-Water Hydrology Relative to Spills

This section discusses the basic principles of pollution movement relative to different hydrogeologic conditions. The hydrogeology of a given location controls the occurrence and movement of ground water and determines, to a considerable extent, the impact a pollutant may have on a ground-water regime.

A spill of a contaminant may occur slowly over a long period of time, or instantaneously. The downward flow of the contaminant may cease for one of three reasons:

- The contaminant will be exhausted to immobility,
- it will encounter an impermeable bed, or
- it will reach the water table.

The downward percolation and lateral migration of a contaminant is governed by the stratigraphic conditions of the soil layers through which the contaminant passes (Figure 1). The rate of migration depends on the viscosity of the contaminant and the permeability of the subsurface.

In the case of exhaustion to immobility, a substance spilled may migrate initially both vertically and laterally through the soil media. Migration ceases when the saturated soil reaches a low point called the "immobile" or "residual" saturation. If this condition develops before the contaminant reaches a water table, ground-water contamination is minimized. Subsequent precipitation and water table fluctuations may carry residual amounts of the product into the ground-water regime. However, there is less risk of significant contamination in this situation than if the plume reached the water table directly.

Precise and detailed data on the nature of the soil and the spilled contaminant are rarely available at the time a spill incident occurs. However, in the event data are available, the volume of soil required to immobilize the spill can be calculated by the following equation:

$$\frac{0.20 \times V}{P \times Sr} = \text{Cubic yards of soil required to attain immobile saturation}$$

V = Volume of contaminant in barrels
P = Porosity of soil, dimensionless
Sr = Residual saturation, dimensionless

After calculating the volume of soil required to immobilize the spill, the depth to the water table and the probability of the contaminant reaching it may be estimated in the following manner. Calculate the volume of soil between the surface of the spill and the top of the water table, making no allowance for lateral migration, so that the volume of soil actually available to absorb the contaminant is understated. If the result is less than the volume determined by the saturation equation, then a distinct risk exists that the contaminant will reach the aquifer.

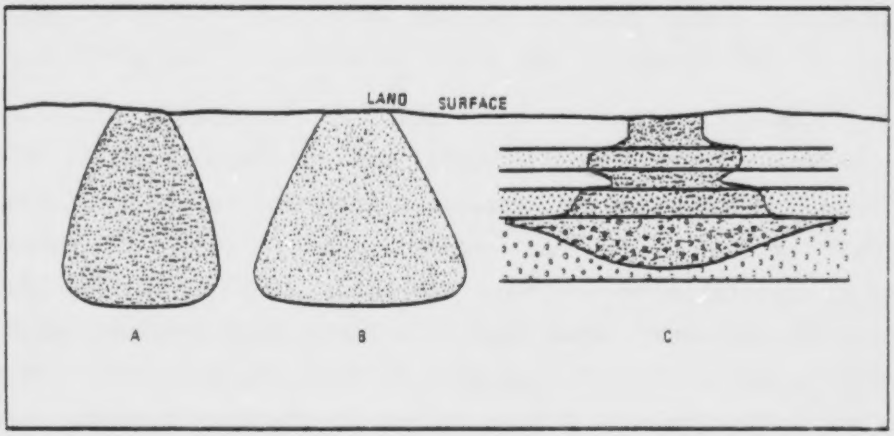

LAND SURFACE
A
B
C

Figure 1. GENERALIZED SHAPES OF SPREADING CONES AT IMMOBILE SATURATION

A – HIGHLY PERMEABLE, HOMOGENEOUS SOIL
B – LESS PERMEABLE, HOMOGENEOUS SOIL
C – STRATIFIED SOIL WITH VARYING PERMEABILITY

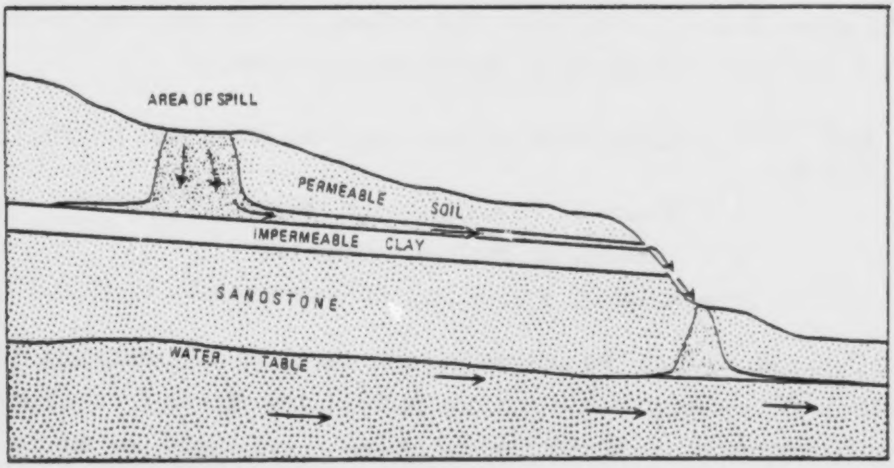

AREA OF SPILL
PERMEABLE SOIL
IMPERMEABLE CLAY
SANDSTONE
WATER TABLE

Figure 2. DEMONSTRATES POSSIBLE MIGRATION TO OUTCROP, FOLLOWED BY SECOND CYCLE OF GROUND WATER CONTAMINATION.

(Courtesy of API Publ. 4149)

As mentioned earlier, a plume of spilled material migrates vertically unless its course is affected by the stratigraphic changes in permeability. Should the material encounter an impermeable layer, or sequence of impermeable layers, the plume will spread laterally until it reaches immobile saturation or until it migrates to a surface outcrop. If this occurs and enough contaminant is in motion, a second stage of soil contamination may begin as illustrated in Figure 2.

This situation occurs only if a water table does not exist above the impermeable barrier or bed. This condition is most common in an arid region or during a dry season and exists as a rule only within several feet of the subsurface.

The migration of a contaminant in the direction of least resistance to the water table usually is the most hazardous effect of a spill on land. As a plume of contaminant, such as oil, reaches the top of the capillary zone located directly above the water table, the substance begins to spread over the water table. The shape of the layer is equivalent to the thickness of the capillary zone and is elongated in the direction of ground-water movement. The plume continues to migrate, forming a shape relative to the permeability features, until it reaches immobile saturation or surfaces at a discharge point. Oil reaching the water table will either be suspended or float. Even though oil is commonly considered insoluble in water, most hydrocarbons either contain enough soluble components or will mix sufficiently with ground water so that it will be unfit for domestic use.

5. Important Hydrogeological Factors Needed to Evaluate the Course of Action Required in the Event of a Spill

Many hydrogeologic factors should be considered to properly assess the procedures needed to mitigate the effects of a spill.

a. Distance to Point of Water Use

The chance of significant contamination to present sources of drinking water decreases as the distance between the source of contamination and a point of ground water use increases. Some reasons include:

- Dilution tends to increase with distance,
- sorption is more complete with increased distance,
- time of contaminant exposure to soil increases with distance, resulting in an opportunity for more complete decay or degradation, and
- sometimes the water table gradient decreases with distance, and therefore, the velocity of flow decreases with the distance from the contamination site.

b. Depth to Water Table

The water table is a determinable but fluctuating boundary between the unsaturated zone and the underlying zone of saturation. The thickness and nature of the unsaturated zone are important considerations in the management of spills affecting ground water. In most places, loose granular materials occupy at least part of the unsaturated zone, and contaminants tend to be stationary except when leached or carried downward by precipitation or by seepage. The great reliance on the unsaturated zone for natural contamination control stems chiefly from the biological and chemical degradation and the sorption of contaminants.

c. Water Table Gradient

The direction of flow and flow rate of ground water are important considerations in evaluating the possibilities of contamination at a specific site. Measurements of water levels in wells and the preparation of a water table map are major steps in solving or avoiding the more serious contamination problems. If a water table map is not available or the cost of making one is not justified, a hypothetical water table map based on topography may be constructed to visualize the general gradient of the water table and thus the general direction of water movement. Of course, it is important to know whether a contaminant is moving toward or away from a water supply.

d. Permeability - Sorption

Because there is a tendency for many contaminants to be retained on earth materials by chemical and physical sorption, an evaluation of the permeability-sorptive capacity of the site should be made. Determining the presence of cracks, fractures and other openings is important because they can provide easy access for a contaminant to an aquifer.

The initial investigation of the geology of a site should be conducted using sources of previously published information which include:

- United States Geological Survey, Ground Water Division (offices in most major cities and state capitals),
- state water resource agencies,
- state geological surveys (usually located in the state capital, and sometimes associated with a state university),
- university geology departments, and
- city water departments.

6. Spill Site Evaluation - A Numerical Rating System

In conducting the Surface Impoundment Assessment program, the Office of Drinking Water has developed a rating system for rapid evaluation of the hydrogeological parameters discussed in the previous section. This rating system determines the aquifer sensitivity of an area where at a minimum cost a surface impoundment is located. It can be used to determine quickly the probability of ground-water contamination potential caused by an accidental spill.

The system examines contamination potential in the upper ground-water system which usually is a water-table aquifer. In a few areas of the country, the first aquifer to be encountered may be an artesian aquifer in which case this rating would also apply. Five basic factors are scored in this system:

(1) the hydrogeology of the unsaturated zone above the aquifer (thickness of unsaturated zone, permeability and general attenuating characteristics of the material, whether consolidated or unconsolidated);

(2) the aquifer transmissivity;

(3) the ground-water quality;

(4) the physical and chemical character of the spilled material such as toxicity, concentration, volume, etc.

(5) the potential for contamination of existing ground and surface water supplies by considering distance and direction of contaminated ground-water movement.

When conducting this assessment, the following steps are taken:

Step 1. Rating the Unsaturated Zone

The hydrogeologic properties of the material underlying the spill site in the unsaturated zone above the aquifer are rated to determine the potential for contaminants to reach the water table. The permeability and sorption characteristics of the earth materials (either consolidated or unconsolidated) may decrease the rate of waste movement and attenuate the waste concentrations to a certain degree. Finer grained unconsolidated material and impermeable consolidated rock inhibit the movement of fluids to the ground water. Additionally, the finer grained earth materials (clays) tend to retard the waste movement by attenuation mechanisms (ion exchange, adsorption and absorption), depending upon waste type and the chemical milieu of the underlying unsaturated zone. The thickness of the unsaturated zone also affects the attenuating capability of the spill site by providing greater contact time of the spilled material with the earth materials and by providing the opportunity for other processes (oxidation, precipitation, biological degradation and filtration) to help attenuate the spilled material.

Although it is acknowledged that contaminated ground water is subject to varying degrees of attenuation as it flows through the aquifer, this rating system focuses primarily on the potential for ground-water pollution. This occurs when contaminants reach the ground water. For this reason, the hydrogeologic factors being rated in this step are those of the material above the aquifer in the unsaturated zone.

Step 2. Rating the Ground-Water Availability

In determining the ground-water pollution potential of the spill site, the overall aquifer property of transmissivity, is important. Transmissivity is the ability of the aquifer to transmit ground water and is related to the hydraulic conductivity and saturated thickness of the aquifer.

Step 3. Rating the Ground-Water Quality

Ground-water quality is a determinant of the ultimate usefulness of the ground water. Consideration of ground-water quality is intended to indicate the background water quality of the aquifer. Ground water presently used for drinking water or having fewer than 500 mg/l total dissolved solids (TDS) is rated highest, and water of more than 10,000 mg/l TDS is rated the lowest quality.

Step 4. Rating of the Physical and Chemical Character of the Spilled Material

The rating of the potential health hazard of the spilled material to drinking water supplies involves the physical and chemical character including toxicity and the volume of the spill. The rating of the toxicity of the spilled material will be characterized according to the waste characteristics identified in the SIC code.

Step 5. Scoring of the Site's Ground-Water Contamination Potential

Upon completion of the first four steps rating the hydrogeologic factors, the aquifer, and the potential waste character, a final score will be determined for that spill site indicating its overall relative ground-water contamination potential.

Step 6. Determination of the Potential Health Hazard to Present Drinking Water Supplies

In order to allow further prioritization of the spill sites by their potential threat to drinking water sources, the distance to present underground and surface drinking water supplies will be rated in conjunction with the determination of the direction of movement of the waste plume (i.e., towards or away from the water supply).

Step 7. Rating the Degree of Confidence

This step allows the spill investigator to indicate his/her confidence in the data used to arrive at the Step 1 through 6 scores. High confidence is given to site specific data sources, and low confidence is given to assumptions based on general knowledge.

Step 8. Miscellaneous Identifiers

This step allows the evaluator to identify special conditions that would not be evident from the numerical scores. For example, the letter A can be added to the score to indicate that the spill site is in an alluvial valley.

Step 9. Recording of Final Score

In this step the evaluator will record the values determined in Step 6 through 8, along with those recorded in Step 5. Upon completion of this step all values for Steps 1-8 will have been recorded and the rating of the ground-water contamination potential will be completed.

The following table shows the general ranges for ground-water contamination and incumbent risks or probability of aquifer contamination. This table can be used as a general guide to determine the degree and urgency of action needed in response to a spill according to the probability of aquifer contamination.

To explain this system in detail, the "Manual for Evaluating Contamination Potential of Surface Impoundments" (EPA 570/9-78-003) is reprinted in Appendix E.

It must be emphasized that the use of the above system is intended as only a standardized methodology for recording the hydrogeologic parameters at a spill site and obtaining a first approximation of the potential for ground-water contamination. The rating system should be utilized to get a quick overview of the spill's threat to ground water and the degree and quickness of the response to the spill required.

To assist in the hydrogeological evaluation of pollution hazards, the following information should also be made available.

- direction and amount of surface runoff
- amount of evaporation and transpiration
- natural and extent of artificial controls exerted on the aquifer, i.e., pumping wells, recharge and discharge areas
- soil attenuation properties

GENERALIZED SPILL SITE RATINGS

Probability of Aquifer Contamination	Step 1 Unsaturated Zone	Step 2 Ground-water Availability	Step 3 Ground-water Quality	Step 4 Contaminant Hazard Potential	Step 5 Ground-water Contamination Potential (1) + (2) + (3) + (4)	Step 6 Potential Endangerment
Very High	9	6	5	9	24-29	9
High	7	5	4	7	18-23	7
Medium	5	4	3	5	12-17	5
Low	3	3	2	3	6-11	3
Very Low	1	2	1	1	1-5	0

The retrieval of such information can be made from existing hydrogeological surveys, pumping test analysis, borehole logging information, geophysical surveys, rainfall and evapotranspiration details and river flow records. Given this information, the hydrogeologist should be able to determine groundwater movement and flow patterns, with the aim of assessing whether or not a given aquifer system affords adequate protection against sources of contamination.

After the determination of aquifer sensitivity is completed, a second stage of susceptibility evaluation is required. This involves an evaluation of the sources of contamination in the vicinity.

The numerical rating system can provide a rapid way of evaluating a spill site for its susceptibility to contamination. However, the spilled material and its properties such as toxicity, biogradability, etc., must be a major consideration in the determination of further action required.

The following are some major factors to be considered:

- Type of contaminants
- Volume in the surrounding area
- Storage types
- Transportation amounts, type and routes
- Preventive techniques used in the area

SECTION 3

SPILL DAMAGE ASSESSMENT TECHNIQUES

1. Monitoring Wells

To detect and evaluate potential or existing ground-water contamination from a land spill, an acceptable monitoring well network should be implemented and consist of the following:

- One line of three wells downgradient from the spill and situated at an angle perpendicular to ground-water flow, penetrating the entire saturated thickness of the aquifer.
- One well immediately adjacent to the downgradient edge of the spill area, screened so that it intercepts the water table.
- One well upgradient from the spill so that it will not be affected by potential contaminant migration.

The size of the spill, hydrogeologic conditions, and budget restrictions are factors which will dictate the actual number of wells used. However, every effort should be made to have a minimum of five wells at the site and no less than one downgradient well for every 76 meters (250 ft.) of spill frontage.

Even if wells are sited according to the information previously described, there is a high probability that one or more of them will not intercept the plume of contaminated ground water because of the heterogeneous and anisotropic nature of aquifers. Also, the aquifer's hydrogeologic paramenters have a significant effect on the shape of the plume. For these reasons, if the budget allows, it is better to have too many monitoring wells rather than too few.

Once contamination is detected, additional lines of wells can be constructed farther downgradient to gauge the dispersion and attenuation of the contaminant. This effort may provide the information necessary for predicting the ultimate fate of the plume, assuming its vertical distribution can be delineated. Construction of additional wells is time consuming and expensive but may be necessary because of regulatory requirements.

A single, properly constructed well adjacent to or within the spill site can indicate whether or not the contaminant is reaching the ground water and gives early warning of potential aquifer degradation. If the contaminant is detected here, the investigator should observe the downgradient wells with extreme caution. The installation of additional downgradient wells at various distances from the spill or the implementation of remedial migration control measures may also be justified at this time. The actual course of action will depend upon site conditions and upon Federal, state and local regulations governing ground-water contamination.

There are potential problems associated with the use of a monitoring well within the spill site. The water monitored is skimmed only from the surface of the aquifer. If any density stratification is occurring, total reliance on this well could give an unrealistic picture of actual contaminant concentration in the ground water. Elevated contaminant concentrations may also be found in water samples if wells are improperly constructed. A backfilled area can act as a conduit for downward movement of the contaminant, introducing it into the aquifer sooner than might have occurred naturally. Proper construction requires the placement of an impermeable seal of either bentonite or cement grout in the annular space between the well casing and the borehole wall. This does not completely guarantee the stopping of downward movement of the contaminant because grout can shrink and bentonite can dry and crack. However, neglecting to use this seal during well installation is almost certain to accelerate and promote ground-water contamination. The value of the information obtained from a well will rarely be outweighed by the above problems, although it is extremely important to be aware of the problems that might occur and to construct wells carefully.

The upgradient monitoring well will provide water samples which will indicate background water quality. This well should be sampled at regular intervals, and the analytical results should be used as a baseline for comparison with results from the spill site and downgradient monitoring wells. Proper water-quality baseline data are necessary for the correct interpretation of the chemical analyses of monitoring well samples. The background well can also provide information on contaminants in the ground water not due to the spill. Elevated nitrates or sulfates from agricultural operations or low pH and high iron characteristic of acid mine drainage are examples of contamination from other sources.

Aquifers differ according to their permeability and porosity. The basic design of a monitoring system at a particular site will require modification according to geologic conditions if the monitoring network is to be effective. Aquifer characteristics should dictate the following:

- monitoring well density, depth, construction and drilling methods;
- probability of successful detection of the contaminant plume;
- sampling methods.

The basic data that should be carefully evaluated in designing a monitoring network include:

- ground-water flow direction;
- distribution of permeable and impermeable ground material;
- permeability and porosity;
- present or future effects of pumping on the flow system;
- background water quality.

Prior to commencing field investigations, the engineer/hydrogeologist study team should first contact state and federal agencies for data and publications concerning existing conditions of the spill site and its vicinity. State environmental departments and the U.S. Geological Survey offices are usually a valuable source of data useful to site investigation. With this information, the study team, familiar with the ground water hydrology in the area, may be able to estimate conditions without actual field measurements. However, every effort should be made to perform field measurements at the site, including the installation of a series of low-cost wells, collecting geologic samples during drillings and measuring water levels in the completed wells. Background water quality can be determined from chemical analysis of water samples from these wells. With good information, monitoring wells can be placed effectively to detect the contaminant plume spreading from the spill site.

2. Surface Water Measurements

Surface waters, such as ponds or streams, in close proximity to a spill may develop a color or oily film on the surface. These bodies of water are usually discharge points for contaminated ground water. Location of these discharge points on a topographic map of the site will often help to provide a reasonable preliminary picture of the ground water flow patterns. In large bodies of water or in areas of rapid flow, the contaminant may be diluted to a point where it can not be detected by visual inspection. In such cases, water samples should be taken and analyzed to establish the presence of contaminants. In a full investigation of surface-water bodies near a spill site, the native biota should be studied for the effects of contaminant migration.

The importance of an analysis of surface-water quality at a spill site is twofold:

- determination of contaminant discharge areas is crucial to establishing an overall hydrogeologic picture;
- surface-water quality degradation is an important component of overall environmental degradation and should be carefully examined.

3. Aerial Photography

Aerial photography has several important uses in spill studies. An aerial photograph will show a spill and the drainage away from it, regardless if it is taken with black and white or color film.

Aerial photography will also detect vegetation stress which may result from the underground migration of a contaminant. Stressed species may include agricultural crops, trees or other plants. Remote sensing of vegetation stress is particularly useful in detecting the extent of spill contamination over large areas.

While advanced vegetation stress may be visible in a color photograph, less advanced stress is best distinguished by using infrared photography.

Multispectral aerial photography has been used in many spill investigations to detect vegetation stress. In this procedure, special equipment is used to determine subtle differences in light reflected at various wave lengths for stressed and unstressed species. Photographic filters which emphasize this difference are used, and several images of the same area are made simultaneously with the aid of a multi-lens camera and the selected filters. Differences between stressed and unstressed vegetation are further enhanced by projecting the images through different color filters and superimposing them on a projector screen.

The usefulness of aerial photography is not limited to the detection of vegetation stress. Accurate contour maps of the land spill surface may be constructed from aerial photographs and are useful in determining hydrogeological characteristics of the spill site. Stereo color photography is used to construct and update these maps. It is important that bench marks, wells and other sampling points be located on these maps because these items will facilitate problem interpretation.

4. Geophysical Well Logging

An accurate evaluation of the sub-surface geology at a spill site is essential to the determination of the direction and rate of movement of a contaminant from a land spill, and the contaminant attenuation capacity of the materials through which it migrates. Geophysical well logging is a useful technique for evaluating these characteristics. It provides indirect evidence of sub-surface formations, indicating the relative permeabilities as well as the depths of the formations by using geophysical measuring techniques. Geophysical well logs are used to supplement the driller's and geologist's logs of the materials penetrated by the borehole.

The most common borehole geophysical operation is electric logging. In this procedure the apparent resistivities of the sub-surface formations and the spontaneous potentials generated in the borehole are recorded. This information is plotted against the depth of the borehole below the ground surface. The measurements of apparent resistivity and spontaneous potential are related to the electrical conductivity of the sediments - a partial function of the size of the grains. Thus fine-grained sediments containing silt and clay will have a lower resistivity than clean, coarse sand and gravel. In addition, a leachate plume may be detectable by an electric log. Electric well logs can be run only in uncased boreholes.

Gamma-ray logging is a borehole geophysical procedure based upon measuring the natural gamma-ray radiation from certain radioactive elements that occur in varying amounts in sub-surface formations. The log is a diagram showing the relative emission of gamma-rays, measured in counts per second, plotted against depth below land surface. Since some formations contain a higher concentration of radioactive elements than others, formation changes with depth often can be accurately determined. For example, clay and shale contain more radioactive elements (e.g., isotopes of uranium, potassium, phosphorus, and thorium) than sand or sandstone. The relative amount of silt and clay in the formations can be estimated by the deflections of the gamma-ray log. Unlike electric logs, gamma-ray logs can be run in single-cased wells.

Geophysical well logging generally is applicable only to those spill site investigations which include test drilling and is therefore not an independent tool. However, gamma-ray logging can be used to gain some understanding of the sub-surface geology at a spill site from existing wells which may be in the vicinity and for which no geologic logs are available.

Since geological well logging requires specialized equipment operated by trained personnel, the task is normally carried out by a firm offering geophysical services. In some instances, larger well-drilling companies are also equipped to perform this service. In such cases, the logging can be included as part of the well-drilling operation.

SECTION 4

SPILL CLEAN-UP TECHNIQUES

1. Soil Removal

Removal of contaminated soil is possible if the contaminant has penetrated only a few feet below the surface and high-capacity earth-movers are available. Soil that is excavated from a spill site should be disposed of at an approved land disposal site. Soil excavation can be considered an initial, rapid response method for the recovery of a contaminant before it reaches the water table.

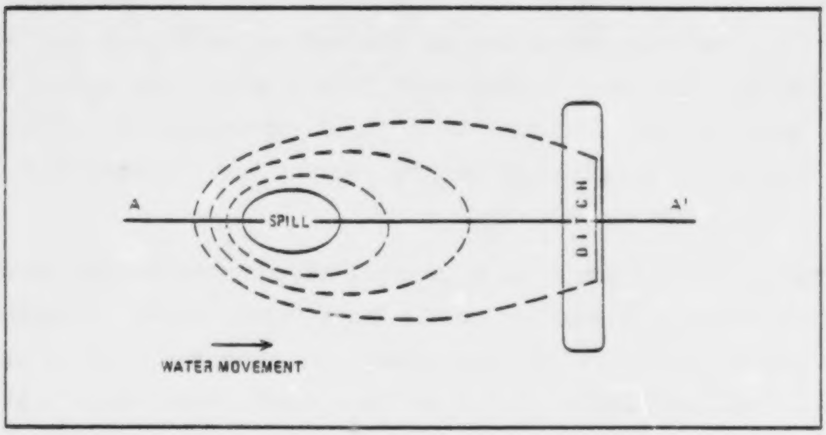
Earth-moving equipment is relatively easy to obtain and usually can be rented from commercial sources in all large urban areas. Equipment may be more difficult to acquire in rural areas, but even there it is usually available. Well-equipped farms will often have useful machinery. City, county and state departments that deal with water, sewers or roads usually have earth-moving equipment. Private and public utilities, such as electric, gas and telephone companies, also can supply excavation equipment.

2. Trenching and Skimming

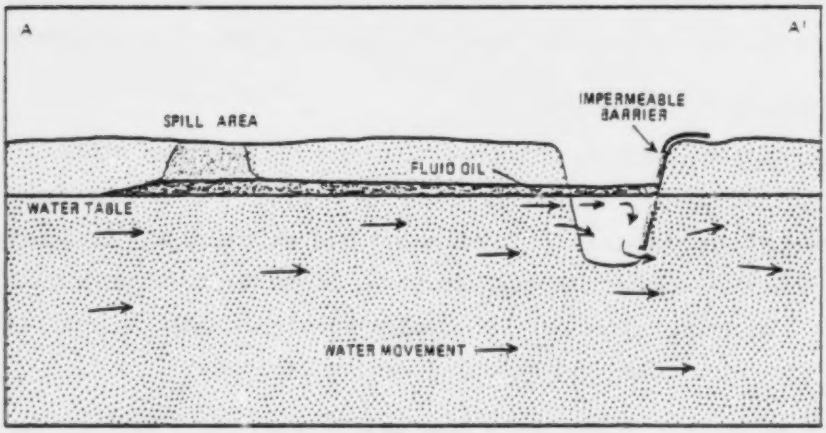
Interceptors such as ditches, trenches or pits can control subsurface movement of contaminated ground water in a water table that is located near the surface (Figure 3). Trenching and skimming may be used as the prime clean-up method or a supplement to other methods described in this section. Equipment required is usually available and, if not, makeshift devices for excavation and skimming can be employed.

Ditches deeper than 6 to 8 feet are impractical, but the depth is basically limited by the type of ditching equipment available and the ability of the soil to support the walls of the excavation without caving. The ditch should extend at least 3 or 4 feet below the water table if the excavation is to be used as a withdrawal point.

Three systems for skimming the water surface in trenches or excavated pits are illustrated in Figure 4. If the ditch is to be a collection point


A
SPILL
A'
DITCH
WATER MOVEMENT

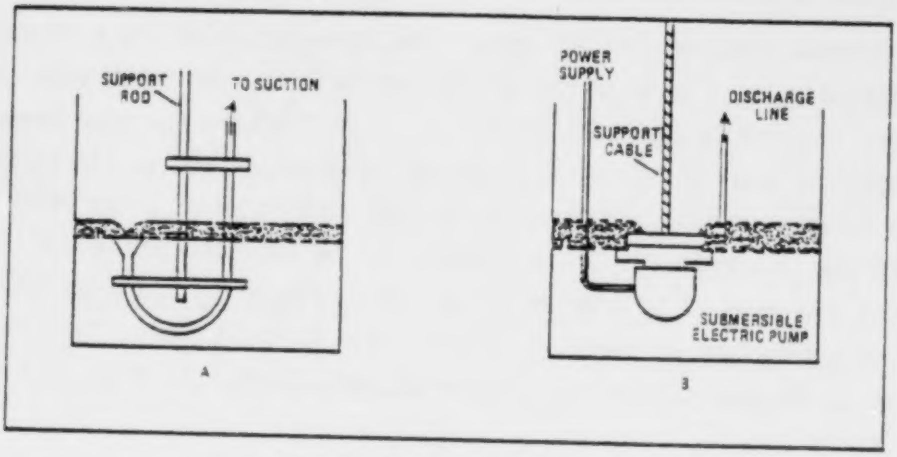
PLAN VIEW


A
A'
IMPERMEABLE BARRIER
SPILL AREA
FLUID OIL
WATER TABLE
WATER MOVEMENT

CROSS SECTION

Figure 3. OIL MOVING WITH SHALLOW GROUND WATER INTERCEPTED BY DITCH CONSTRUCTED ACROSS MIGRATION PATH.

(Courtesy of API Publ. 4149)


SUPPORT ROD
TO SUCTION
A
POWER SUPPLY
SUPPORT CABLE
DISCHARGE LINE
SUBMERSIBLE ELECTRIC PUMP
B

A Flotation Device May be Substituted for the Handling Cable or Rod

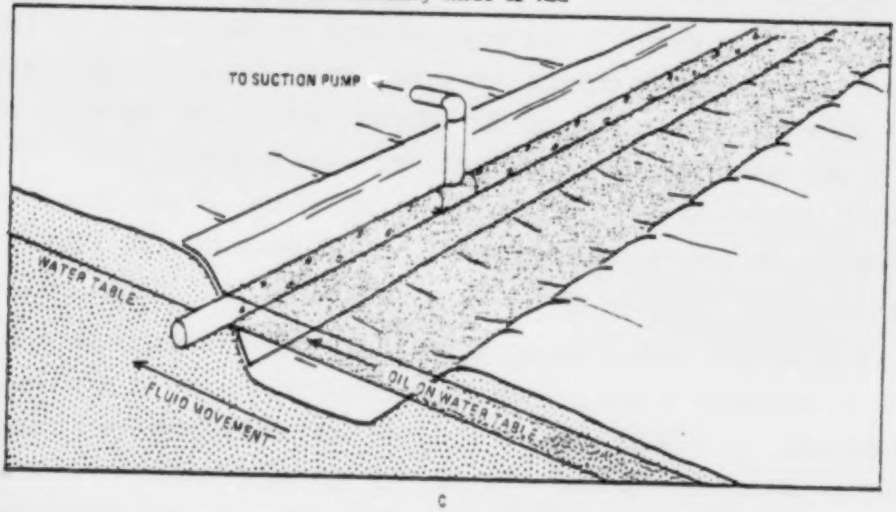

TO SUCTION PUMP
WATER TABLE
OIL ON WATER TABLE
FLUID MOVEMENT
C

Figure 4. THREE SYSTEMS FOR SKIMMING WATER SURFACE IN DITCHES OR WELLS.

(Courtesy of API Publ. 4149)

for skimming, its downstream wall should be lined with an impermeable material such as polyethylene film as shown in Figure 3. An impermeable film will block floating oil, but permit water to pass below. Skimming must be continuous or collected oil will tend to move to the ends of the ditch and pass around the barrier.

Ditches need not be left open. One approach is to lay a string of perforated culvert pipe in the bottom and backfill the ditch with very porous material such as broken rock or gravel. Fluid enters the pipe through the perforations and can be removed through an opening left in the backfill. Sometimes an intercepting ditch can be filled with straw or other absorbent to absorb the contaminant. The absorbent can be replaced periodically as it becomes saturated. It must be noted that a trench is not a barrier to control subsurface movement of contaminated ground water. The trench must either be skimmed continually or pumped sufficiently to make it a suitable collection point.

3. Recovery Wells

Vertical withdrawal wells are used when the water table is too deep for the use of interceptor trenches or pits. This clean-up method is more efficient when the permeability of the aquifer is high and the depth of the aquifer is adequate to allow construction of a high-capacity well. In addition, vertical withdrawal wells can be effective in shallow aquifers when interceptor trenches cannot be used because of interference of such things as buildings, highways, tunnels, conduits and pipelines.

This removal method establishes a depression in the water table sufficient to concentrate and prevent the further migration of a non-water soluble contaminant. A withdrawal well will work effectively where hydraulic conditions are such that pumping will depress the water table significantly. In this situation, the permeability and other hydrogeologic conditions allow a significant cone of depression of the water table. This causes the contaminated ground water to migrate toward the center of the depressed cone and be removed through the pump. Many common spilled materials such as oil products are lighter than water and have a low solubility. Materials of this type may be withdrawn and separated by this recovery method.

A standard procedure to determine the size and rate of development of the cone is to drill several monitoring wells in straight lines adjacent to the withdrawal well. By the observation of fluid levels, the time and amount of drawdown can be determined as well as the further expansion of the depression cone. Withdrawal rates should be adjusted to maintain a cone large enough only to contain the contaminant.

The average cone of depression is shallow, with horizontal distances measured in feet and vertical distances in inches. If the water table is horizontal, a shallow depression normally will suffice to confine the floating contaminant. See Figures 5 and 6. However, water tables are usually inclined and the cone must be deep enough to reverse the resulting gradient. The point at which the reversal occurs is the water table "divide". See Figure 7. If the contaminant is to be contained effectively, the divide must lie beyond the contaminated area.

4. Biodegradation of Petroleum and Chemical Spills

All natural soil, ground water and surface water ecosystems include a group of organisms which are capable of biologically degrading complex organic molecules. These organisms are mostly microscopic, and consist mainly of bacteria and fungi. Although petroleum and organic chemicals are toxic to most plants and animals, some decomposing bacteria and fungi can use these substances for nutrient supplies. For this reason, development of spill abatement technologies based on biodegradation is a promising field, and has recently received much attention.

Although biodegradation is a natural process and will occur without any stimulation, its major drawback is that it normally proceeds at a very slow rate in soil or ground-water systems. Thus, the technologies being developed to combat spills in these systems are directed toward speeding up biodegradation by ensuring a good supply of the materials which normally limit the growth of bacterial and fungal populations. These materials, the most important of which are oxygen, nitrogen, phosphorus and water, are injected or allowed to percolate into the soil or ground-water system. In some cases, an activated sludge culture of bacteria or fungi is also added to supply a baseline population of these organisms. Since soil and ground waters normally

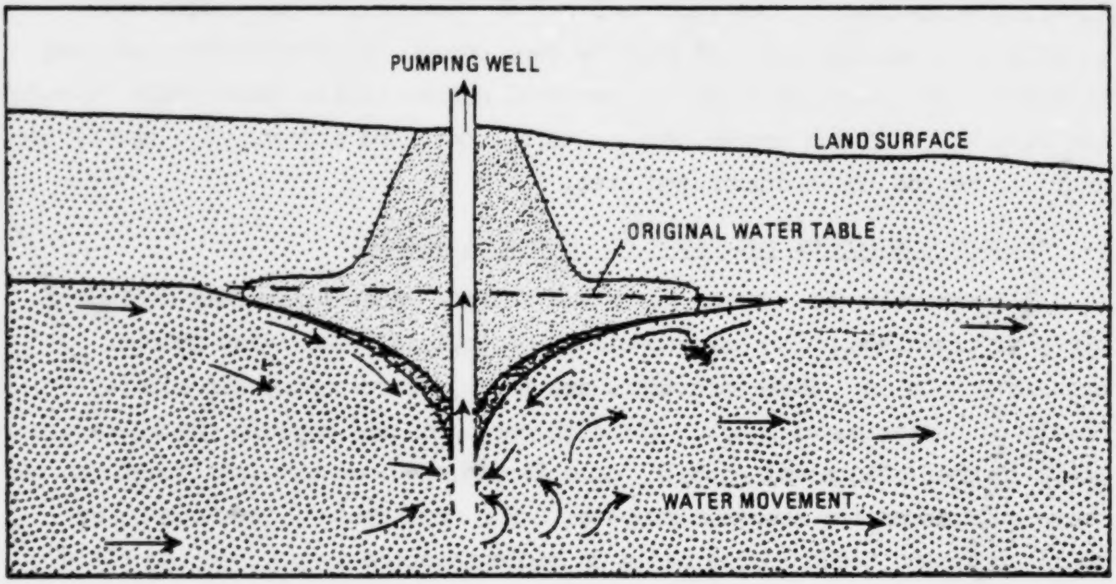

PUMPING WELL
LAND SURFACE
ORIGINAL WATER TABLE
WATER MOVEMENT

Figure 5. OIL ON WATER TABLE IS TRAPPED IN CONE OF DEPRESSION CREATED BY DRAWDOWN OF PUMPING WELL.

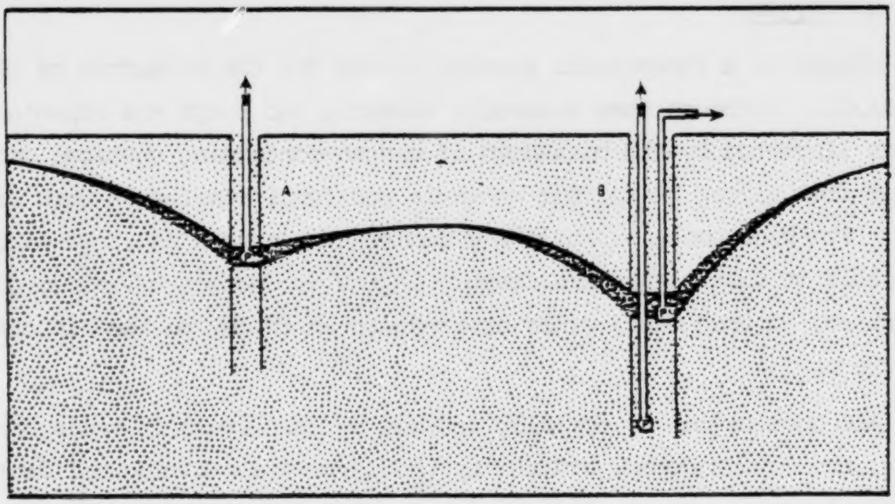


Figure 6. Use of Two Wells for Recovery.

WELL A IS MAINTAINING DEPRESSION AND RECOVERING OIL IN SINGLE OPERATION BY DRAWING FLUID SURFACE DOWN TO PUMP LEVEL.

WELL B IS MAINTAINING DEPRESSION BY PUMPING CLEAN WATER FROM BELOW WATER TABLE. FLOATING OIL IS RECOVERED BY SUCTION PUMP AT FLUID SURFACE.

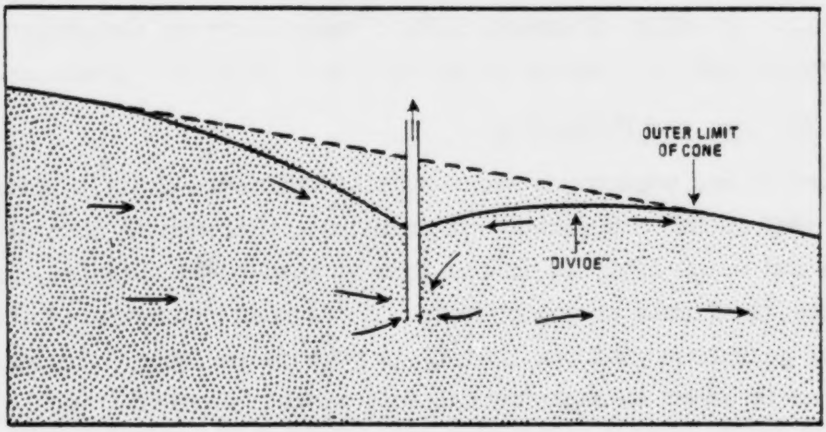


Figure 7. DRAWDOWN CONFIGURATION OF WELL PUMPING FROM INCLINED WATER TABLE.

FLUID AT THE SURFACE OF THE WATER TABLE BETWEEN THE DIVIDE AND OUTER LIMIT OF CONE WILL NOT BE TRAPPED, BUT WILL MOVE DOWN-GRADIENT WITH THE WATER.

(Courtesy of API Publ. 4149)

contain sufficient quantities of the trace elements necessary for growth and metabolism by these organisms, these materials are not usually added. A short discussion of the roles of the major factors (oxygen, nitrogen, phosphorus and moisture) in controlling biodegradation follows.

a. Oxygen

Oxygen is a fundamental element needed for the breakdown of organic materials. Although some anaerobic bacteria and fungi are capable of using oxygen liberated by the breakdown of oxygen-containing chemical compounds, the use of free oxygen by aerobic bacteria and fungi results in much faster breakdown. The biochemical reactions which require oxygen and take place within the cells of these organisms, result in the production of carbon dioxide, water, and in some cases other by-products which may be used in the synthesis of more cells.

Although oxygen is normally present in low levels in soils and ground water, the oxygen demand created by the large-scale biological degradation of petroleum or other organic compounds can create situations where the rate of degradation is limited by the amount of oxygen in the system. This is particularly critical in ground-water systems, where dissolved oxygen concentrations are usually minimal. To correct this problem, air can be pumped into wells. In soils, frequent tilling helps increase the oxygen available to microorganisms and results in an increased rate of degradation.

b. Nitrogen and Phosphorus

Nitrogen and phosphorus are essential nutrients for all living things, and are used in the manufacture of proteins. Nitrogen is most available to bacteria and fungi if it is in the form of ammonia or nitrates, and phosphorus is most available as phosphates. It has been demonstrated that biodegradation of petroleum products in soil is much faster when nitrogen/phosphorus fertilizer is added to experimental soil plots. Another investigator showed that the addition of a nutrient mixture consisting primarily of nitrogen and phosphorus compounds greatly increased the rate of biodegradation of gasoline in a ground-water system.

c. Moisture

Since nutrients are transported into the cells of bacteria and fungi by water, some moisture is required if biodegradation is to occur. Optimal conditions for the breakdown of organic compounds in soil are found when the soil is moist and friable. Although moisture is necessary, too much can be harmful by interfering with the circulation of oxygen. This is one of the main reasons why biodegradation occurs much more quickly in soil than in ground waters. Surface water systems have an entirely different situation. The biodegradation of oil is faster in the water column than in the sediments, which are usually poorly oxygenated.

Another problem related to moisture is that in saturated conditions, petroleum or other organic chemicals with a specific gravity less than that of water may form a layer on top of the saturated zone. This layer presents much less surface area per unit volume for attack by the bacteria and fungi than if the spilled material were sorbed over a large volume of soil. Thus too much moisture, or too little moisture, can severely retard the rate of biodegradation. It is especially critical in instances of ground water contamination that oxygen and nutrients be supplied to help speed up biodegradation.

d. Other Factors

Other factors besides oxygen, nitrogen, phosphorus and moisture also affect the rate of biodegradation. The temperature of the soil or ground water helps control the metabolic rate and growth of populations of bacteria and fungi. As the temperature increases, so does the rate of biodegradation. The density and composition of the bacterial/fungal community is also important - acclimated cultures of these organisms can respond quickly to influxes of organic materials and generally do not exhibit population crashes typical of unacclimated communities. Commercial activated sludges similar to those used in sewage treatment are available from some suppliers to consume petroleum products in areas contaminated by spills.

One other factor which is extremely important in determining the rate of biodegradation is the type of material spilled. The susceptibility of organic chemicals to biodegradation varies widely. In general, it appears that the more highly halogenated an organic chemical is, the more resistant it is to biodegradation. It is generally believed that the paraffin fractions of petroleum are more susceptible to biodegradation than the aromatics. However, it has been reported that, in tests with five different oils applied to soil plots, the paraffin fraction of the oils was not degraded faster than any of the other fractions.

e. Case Histories

At this time, the techniques used to stimulate biodegradation have been used only rarely in combating spills. However, the results are promising. The works of R. L. Raymond, V. M. Jamison and J. O. Hudson, Jr., have been instrumental in pioneering this field. (See references cited in Bibliography, Section 6). In a study of a gasoline contaminated aquifer in Whitemarsh, Pennsylvania, these investigators determined that the lack of availability of oxygen, nitrogen and phosphorus was limiting the biodegradation of gasoline. After performing laboratory studies on the rates of bacterial decomposition of the gasoline, they stated that "By addition of these... nutrients to several selected wells in the system, the removal of gasoline might be accomplished in a matter of months rather than in the years it would take to physically remove it."

In a study of the rate of biodegradation of oils in soil, it was shown that the addition of fertilizer greatly increased the rate of biodegradation.

McKee found that the number of gasoline-degrading bacteria in samples from contaminated wells was related to the concentration of gasoline in the sample. Although there had been no addition of nutrients or oxygen, there is some evidence that biodegradation would have resulted in the degradation of the gasoline over a period of years.

f. Advantages and Disadvantages

Although biodegradation is by no means a proven technique, it is already apparent that there are certain advantages and disadvantages. Advantages of the approach include:

- It can efficiently remove small concentrations of pollutants which would be difficult to separate by physical means.
- Water-soluble pollutants which are susceptible to biodegradation would be extremely difficult to remove by other clean-up techniques.

- Waste disposal is not a problem associated with this clean-up technology.
- In some cases, biodegradation may be a much faster process than other removal techniques.
- In ground-water contamination, the treatment moves with the contaminant plume.

Disadvantages include the following:

- Bacteria and fungi can create a viscous slime, which could plug up wells and soils and cut off the supply of oxygen, nutrients and moisture.
- Residues may create taste and odor problems.
- Even though the organisms involved are very small, in some geologic formations with extremely small pore size, water and cell movement may be hindered.
- Continued injection of oxygen and nutrients may be necessary to sustain a high rate of degradation, especially in ground-water systems.
- Where the pollutant is relatively concentrated, there may be relatively little surface area for the organisms to attack, and biodegradation may be slower than physical removal processes.

In summary, biodegradation may not be the best technology to employ for all spills, but as more research is completed, it appears that it may be the best choice in some circumstances, and it is probably a valuable supplement to other clean-up techniques in others. Most of the information available on biodegradation relates to spills of petroleum products, but is certainly applicable for other organic substances as well. It is conceivable that biodegradation techniques may be used in the future for combating spills of solutions of inorganic materials such as antimony, mercury, arsenic and selenium. These elements can all be reduced by bacteria to form gaseous complexes which would be mobile in the environment and could result in their liberation from contaminated soil or ground-water systems. At any rate, currently existing technology for stimulating biodegradation of petroleum and organic chemicals is a valuable tool for ameliorating spills and should be considered as an alternative or supplement to other, more well-known, spill clean-up techniques.

5. In-Place Detoxification

The present most widely used clean-up techniques for land spills are excavation and hauling to a landfill or flushing the affected area with water. Although these methods may be appropriate for some spills, other approaches may be needed when ground water is threatened, when a large soil mass is contaminated or when no suitable disposal site is available. An alternative method is a mobile treatment system which will provide in-place detoxification of hazardous materials spilled on soil.

The objectives of an in-place detoxification system are to contain and treat the spill. Containment is achieved by surrounding the spill with injections of grouting material which envelops the contaminated area. The isolated area is then chemically treated to achieve oxidation/reduction, neutralization, precipitation or polymerization which detoxifies the spilled contaminant.

The treatment system can be mounted on a truck-like vehicle. The grout or chemicals are mixed in two fiberglass tanks in alternate batches. The grout is transferred by positive displacement pumps which provide the most control and simplest operation. The vehicle is also equipped with an air compressor and a diesel-electric generator. These will power the "air-hammer" type device used to drive the injectors into the ground. Tanks for detoxification of chemicals can be mounted on the vehicle.

6. Foams

The advantage of using foam on spills of hazardous materials is the foam's ability to isolate the spill surface and partially control the vapor concentration above the spill. Presently, two types of foam are used in the area of fire suppression. These are the low expansion protein foams made by mechanical agitation and the high expansion surfactant foams generated by impacting foam on a screen or net.

The most extensive use of foam in spill control has been for the isolation of hydrocarbon fuel spills. Both high and low expansion foams are used to control and extinguish hydrocarbon chemical fires. The foam provides protection for a limited amount of time as all volatile materials have some degree of permeability through foam. Care must be taken to use foams only when they have been proven effective for a specific situation.

High expansion foam is used exclusively to treat cryogens in this case. Vapor dispersion and reduction of flame intensity are the two major benefits provided by foam when treating cryogens.

Another application of foam is to apply water to aggressive water reactive materials. By using foam, water can be added gently to such reactive materials as SO_3 and $SiCl_4$. In this way the concentration of the toxic species can be slowly reduced to the desired level.

7. Gelling Agents

An effective method of containing and controlling spills of hazardous materials on relatively non-porous surfaces is that of applying a gelling agent to the contaminated area. Gelling agents interact with the hazardous material to form a gel that can be easily removed by mechanical means. This immobilization prevents the spill from spreading and therefore minimizes contamination of soil and water.

There are various gelling agents with different gel rates, application techniques and production costs. Most are dispersed by a hydraulically-driven auger-fed pneumatic conveyor and powered by a gasoline engine. These systems are housed in a waterproof utility trailer designed to be towed by a 3/4-ton pick-up truck.

Field tests have shown that the application of gelling agents is a practical solution for both small and large scale spills. The system can be operated with low technology personnel and can be built from readily available commercial equipment. The major drawback to this clean-up method is that gelling agents will not immobilize material at depths greater than 10 centimeters.

SECTION 5

LAND SPILL PREVENTION AND CONTROL TECHNIQUES

The use of effective spill prevention and control techniques reduces the probability of ground water contamination in the event of a land spill. The hazard potential of various materials, the spill problems they pose and potential effects on the surroundings must be clearly recognized. Even with the most care, spills will occur as long as there is a possibility of human error and mechanical failure. Presently, the technology to mitigate the effects of a spill that has contaminated ground water is less developed than the technology available to either prevent or contain a spill. Also, most of the prevention and control emphasis in this document is directed toward underground tanks and pipelines which are the major source of undetected spills affecting the quality of ground water supplies. This section of the document describes currently used prevention and control techniques.

1. Prevention Techniques

a. Underground Tank Corrosion and Leak Testing

The following are the basic techniques used to detect leaks and to prevent corrosion of underground storage tanks.

(1) Coatings

Many service stations in the United States use coatings such as good quality epoxies, asphaltic paints, mastics and hot-applied bituminous materials to prevent corrosion of their underground storage tanks. Some of these materials deteriorate with time and may be useful for only a few years. Coatings reduce the amount of tank exposure to corrosive elements in the surrounding soil. Accelerated corrosion often occurs at breaks or flaws in the coating. It is best to combine coatings with cathodic protection.

(2) Cathodic Protection

This technique protects underground storage tanks by preventing electrolytic corrosion caused by stray electrical currents. Connections are made to opposite ends of a storage tank and a small power source is connected, resulting in a polarized tank. The current passing through the tank interferes with, and reduces the effect of, any external electrical currents.

There are two basic types of cathodic protection: galvanic and impressed current. Each is widely used to protect buried tanks. A general description of each is given below.

- Galvanic Cathodic Protection

Galvanic cathodic protection, sometimes referred to as sacrificial anodes, is used for the protection of pipelines as well as for tanks. Knowledge of the soil resistivity, the quality of the coating material used, the size of container and the presence or absence of insulation are required for the calculation of the number of anodes needed. The most common type of anode is magnesium, although zinc anodes are used in low resistivity soils (below 1,000 ohm-cm). It is good practice to coat the tanks because the number of anodes required increases with the unprotected area of the tank. During the past few years, "pre-engineered" cathodic protection has been developed and usually consists of a tank with a galvanic anode on each end.

- Impressed Current Protection

Impressed current is the form of cathodic protection used to protect most service station tanks. It works by passing DC current, supplied by an AC-DC transformer-rectifier through the circuit consisting of the tank, anodes, soil and the rectifier. The anodes are usually made from cast iron, graphite or scrap steel. Because impressed current systems are adjustable over a wide range, even uncoated or bare tanks can be protected by increasing the driving voltage.

Impressed current systems require a constant source of current and when protecting bare or poorly coated tanks, large amounts are necessary. This energy demand may be a problem, depending on the availability and cost of electricity. There are periodic inspection and maintenance costs also.

A stray current problem may occur when there are other metallic structures in the area and the current is picked up by these structures. This will leave the tank unprotected and can lead to corrosion. For this reason, field tests are required to assure adequate protection.

b. Storage Tank Liners

Storage tank corrosion is one of the major causes of tank failure and leakage. In the case of gasoline storage tanks, it is not the gasoline itself that causes corrosion, but rather the occluded air and water. When the temperature of a hydrocarbon drops from 140°F to 80°F, as much as 0.5 lb of water can be condensed from 100 lb of hydrocarbon. To insure against corrosion, tanks can be lined with epoxy resins.

Epoxy coatings provide a solid, glass-hard inner protective wall that prevents corrosion and subsequent leaking. Old tanks with leaks can be lined with epoxy resin for less than it would cost to purchase a new tank, and it would be more corrosion resistant. Over 70 percent of repaired storage tanks are lined with epoxy resins.

The process of epoxy lining a storage tank takes only two days. The tank must first be emptied and aerated. It is then sand blasted to clean metal. The epoxy resin is applied and the tank is permanently sealed shut with a pressure-proof cover.

c. Leak Detection

There have been numerous instances where large amounts of gasoline have leaked from storage tanks at service stations. Most of these leaks were not discovered for quite some time. If they were detected somewhat earlier, the harmful effect on the environment could have been lessened significantly. Leak detectors for installation on gasoline service station pumps are currently available and effective.

d. Pipeline Monitoring by Acoustic Emissions

Acoustic emissions are internally generated sounds produced by a material when placed under stress. This phenomenon can be effectively used for early warning and immediate response to hazardous spills developing from pipeline ruptures or leaks. The equipment necessary for monitoring acoustic emissions is available commercially and can give instantaneous answers regarding the stability and condition of pipelines over an infinite variety of field conditions.

Although some acoustical emissions, like wood splitting or cracking, are audible to the naked ear, most are above or below our hearing range. To monitor these sounds, a transducer must be placed on the pipeline. The transducer transforms the acoustical emissions into electrical signals which are then amplified, filtered and recorded. The records are interpreted to determine the location and severity of damage.

e. Volume Sensing Tapes

These small, compact sensing tapes offer numerous applications from storage facilities to various transportation modes to monitoring ground waters. The sensing tapes are capable of measuring any type of bulk material that flows providing their bulk densities are between 15 and 200 lb/ft^3.

Having uniform resistance per unit length, the sensing element provides a highly linear output signal, with errors substantially independent of sensor length.

The sensing element is usually gravity-suspended through a small access hole in the tank roof. Tank walls are not breached, and installation can often be performed while the vessel is in use.

There are many applications of the sensing tape level-measurement equipment. In the petroleum industry, uses range from automation of cargo loading and unloading to tank farm inventory monitoring and control. Many plastics, such as polyethylene, polypropylene, polystyrene, polyvinyl chloride and ABS are measured with sensing tapes to determine quantities. Chemical compounds can also be monitored using sensing tapes due to its corrosion resistant properties.

f. Fiberglass Underground Storage Tanks

An alternative to the use of steel tanks is the use of fiberglass storage tanks. Fiberglass is strong enough to withstand soil and loading stresses and it resists hydrocarbon corrosion. Although not difficult to handle or install, care must be taken to insure correct installation as indicated by the manufacturer. Incorrect backfilling can result in cracking. Fiberglass storage tanks will usually be serviceable for at least twenty years.

2. Control Techniques

a. Tank and Pipe Leak Plugging

The problem of leaks in pipelines, storage facilities and transportation vehicles has indicated the need for a portable, easy to use device that will plug up these leaks. Such a device has been developed through the experimental stage. The wide range of its applications combined with the simplicity of its operation make this leak plugging system seem very practicable.

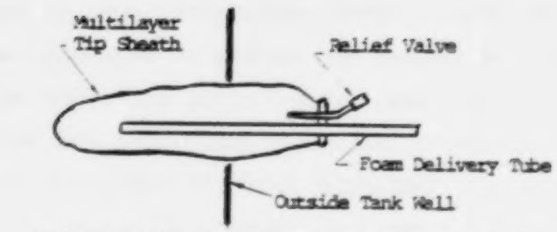
A schematic diagram of the leak plugger is shown in Figure 9. It can be operated by one unskilled employee dressed in protective clothing. At one end of the unit is the applicator top which must be inserted into the rupture where the tank is leaking. The size of the tip differs according to the size of the hole to be plugged. When triggered, the tip expands as foam is forced into it. When the foam hardens the applicator tip is released from the main frame and the leak is sealed. Another important part of the leak plugging system is the tandem cylinder. Two urethane foam components are stored under pressure and ready for use. When the system is applied, the foams are propelled by a CO_2 cartridge to the applicator tip. The tip swells, the foams harden, the tip is released from the unit and the leak is plugged. The system can be used quickly and repeatedly as it only requires about one minute for the foams to harden and, to repeat the procedure, one simply replaces the applicator tip, CO_2 cartridge and the tandem cylinders.

b. Surface Preparation Control Techniques

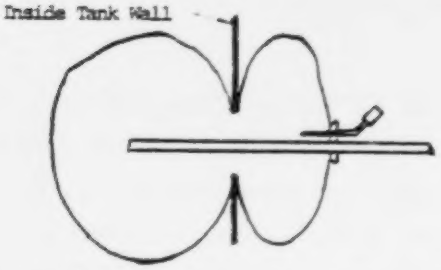
When spills or leaks occur within an above-ground storage area, contamination of the soil and migration of the contaminant to the water table may occur. Several techniques are being used to contain above-ground spills. These include soil treatment with sodium bentonite, plastic liners and underground barriers.

(1) Sodium Bentonite Soil Treatment

This substance has a unique molecular structure that allows it to absorb many times its own weight of substance, swelling enormously in the process - in most cases up to 10-16 times its dry bulk volume - to form an impermeable gel barrier.


Multilayer Tip Sheath
Relief Valve
Foam Delivery Tube
Outside Tank Wall

Applicator Tip Just After Insertion into a Hole


Inside Tank Wall

Applicator Tip Expanded by Initial Gas Flow

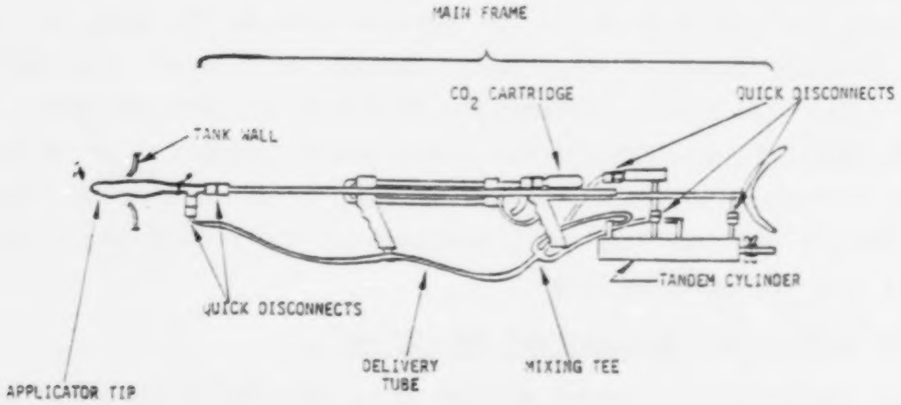

MAIN FRAME
CO2 CARTRIDGE
QUICK DISCONNECTS
TANK WALL
TANDEM CYLINDER
QUICK DISCONNECTS
DELIVERY TUBE
MIXING TEE
APPLICATOR TIP

Figure 8. Schematic of a Commercially Developed Leak Plugger.
(Figures from EPA-600-12-76-300, 1976)

In most sodium bentonites, the swelling ability is long lasting and reversible. It can be dried and re-swelled an infinite number of times. When mixed with soil around a storage tank and wetted, the sodium bentonite swells, pressing against the soil particles and filling the voids between the particles. It usually never permanently sets or hardens, so it remains flexible, naturally expanding and moving to self-seal any cracks. The swelling action forms a tight seal around pipes and other equipment that protrude from a tank, eliminating difficult installation and sealing problems. Installation instructions are available from the sodium bentonite supplier.* Bentonite treated layers may lose their structural and sealing integrity when in contact with acidic fluids.

(2) Liners

Ultra-wide linings are fabricated from polyvinyl chloride, Hypalon, and chlorinated polyethylene (CPE). The high quality lining materials have proved to be extremely durable. All the materials are tough, resilient and resistant to biodegradation. The use of PVC, Hypalon or CPE will depend on the application. Linings are available in a variety of thicknesses ranging from 10 to 40 mils, or greater. The thickness will depend on the specific application and on the material selected. Since mechanical damage is always possible, all membranes and particularly the thinner ones, should be protected with an earth covering. If covering is not possible, greater thickness of a reinforced material should be considered. Linings are fabricated in widths up to 100 feet. Two or more sections may be joined to cover any area. Throughout the United States, linings and covers are in widespread use to prevent seepage of industrial wastes through the soil to ground water and streams. These linings cost far less than rigid materials such as concrete and asphalt used for earth sealing.

(3) Underground Barriers and Cut-off Walls

An impervious underground barrier as illustrated in Figure 10 is a concrete-like cut-off wall reflecting methods and technology ideal for containment of oil, chemical and leachate seepage. Installation can be rel-

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* American Colloid Company

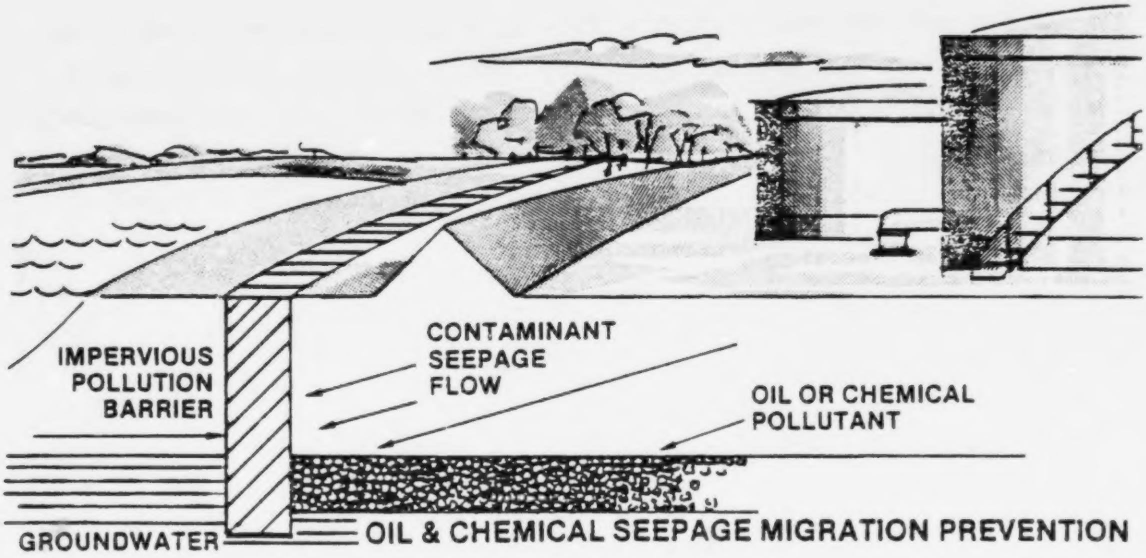
IMPERVIOUS POLLUTION BARRIER
CONTAMINANT SEEPAGE FLOW
OIL OR CHEMICAL POLLUTANT
GROUNDWATER
OIL & CHEMICAL SEEPAGE MIGRATION PREVENTION

Figure 9. Underground Barrier and Cut-off Wall.

(Courtesy of Chem-Bar.)

atively fast and uncomplicated which permits rapid compliance with pollution control directives. These permanent barriers are ideally suited to prevent the pollution of ground water, rivers and lakes. They may be installed at a low cost with minimum surface disturbance and facility operation. Extensive subsurface experience in geology, foundation engineering and hydrology should be applied to the design and fabrication of an underground pollution barrier. This technical know-how will ensure a permanent cutoff wall of the highest quality to prevent ground water pollution.

It has been conclusively proven that if a barrier does not reach to an aquiclude below ground waters, a floating contaminant will collect against the barrier and flow under it. Any contaminant barrier must have associated pumping recovery of the contaminant as it collects. Further, if a barrier encircles the facility and reaches the aquiclude, a lake will be formed unless dewatering is accomplished.

SECTION 6

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APPENDIX A

GENERAL DESCRIPTIONS OF THE 24 GROUND WATER PROVINCES IN THE UNITED STATES

Figures A-1 and A-2, at the end of this appendix, show the general distribution of ground water reserves and the U.S.G.S. ground water provinces in the U.S., respectively. The following are general descriptions of the 24 provinces as identified on Figure A-2.

A. Atlantic Coastal Plain Province

Water is derived in rather large quantities from Cretaceous, Tertiary, and Quaternary strata, which are comprised chiefly of sand and gravel interbedded with clay. Large supplies are obtained from alluvial gravels in the Mississippi Valley and adjacent areas. This province includes extensive areas of artesian flow. The ground water ranges from low to high in mineral content.

B. Northeastern Drift Province

Principal ground water supplies in this province come from glacial drift. The glacial till yields small supplies to many springs and shallow wells. The outwash gravels supply large amounts of water, notably on Long Island in New York. Many drilled rock wells have small supplies, chiefly from joints in crystalline rocks or in Triassic sandstone. Ground water is generally low in mineral content.

C. Piedmont Province

Water that is generally low in mineral matter is supplied in small quantities by the crystalline rocks and locally by Triassic sandstone. Many shallow dug wells are supplied from surface deposits or from the upper decomposed part of the bedrock. Many drilled wells of moderate depth are supplied from joints in the crystalline rocks. Some wells in Triassic sandstone yield rather large supplies.

D. Blue Ridge-Appalachian Valley Province

This is a region of rugged topography with numerous springs which generally yield water of good quality from Paleozoic strata, Pre-Cambrian crystalline rocks, or Post-Cambrian intrusive rocks. The water supplies are derived chiefly from springs, spring-fed streams and shallow wells.

E. South Central Paleozoic Province

The ground water conditions are in general rather unsatisfactory. The principal sources of water supply are the Paleozoic sandstones and limestones. The Paleozoic water supplies are meager or of poor quality throughout a considerable part of the province. Deep Paleozoic water is high in mineral content. In many of the valleys, large water supplies are obtained from glacial outwash and other alluvial sands and gravels.

F. North Central Drift-Paleozoic Province

Most water supplies are derived from the glacial drift, where the water is generally hard but otherwise good. Numerous drilled wells obtain large supplies of water from glacial outwash or from gravel interbedded with glacial till. Many drilled wells end in Paleozoic sandstone or limestone and receive ample supplies of water. The deeper Paleozoic waters are generally high in mineral content and in many places are unfit for use; the shallower Paleozoic waters are commonly of satisfactory quality except that they are hard. In many areas flowing wells can be obtained from glacial drift and Paleozoic aquifers.

G. Wisconsin Paleozoic Province

Most of the water supplies are obtained from wells of moderate depth drilled into Cambrian or Ordovician sandstone or limestone. These wells, as a rule, yield ample supplies of hard but otherwise good water. In many of the valleys, artesian flows are obtained from the Paleozoic aquifers. The region is devoid of water-bearing glacial drift except in the valleys, where there are water-bearing outwash gravels.

H. Superior Drift-Crystalline Province

In most parts of this province, satisfactory water supplies are obtained from glacial drift. Where the drift is thin, water supplies are generally scarce, because the Pre-Cambrian crystalline rocks in most places yield only meager supplies, and, as a rule, there are no intervening Paleozoic, Mesozoic or Tertiary formations thick enough to yield much water. The drift and rock waters range from waters of low mineral content in Wisconsin to waters of high mineral content in the western and northwestern parts of the province.

I. Dakota Drift-Cretaceous Province

The two important sources of ground water in this province are the glacial drift and the Dakota sandstone. The drift supplies numerous wells with hard but otherwise good water in nearly all parts of the province. The Dakota sandstone has extensive areas of artesian flow which supply many strong flowing wells, a considerable number of which are more than 1,000 feet deep. The Dakota sandstone waters are high in mineral content but are usable for domestic supplies. Although the water from most parts of the formation is very hard, water from a few strata is soft.

J. Black Hills Cretaceous Province

The conditions in this province are, on the whole, unfavorable with respect to shallow water supplies because most of the province is underlain by the Pierre shale or by shales of the White River group (Oligocene). The principal aquifer is the Dakota sandstone, which underlies the entire region except most of the Black Hills. This sandstone will probably yield water wherever it occurs, but over considerable parts of the province it is far below the surface. In some localities underlain by shale, small supplies are obtained from shallow wells. In the Black Hills, water is obtained from a variety of sources, ranging from Pre-Cambrian crystalline rocks to Cretaceous or Tertiary sedimentary rocks.

K. Great Plains Pliocene-Cretaceous Province

The principal aquifers of this province are the late Tertiary sands and gravels of the Ogallalla formation and related deposits and the Dakota sandstone. The Tertiary deposits underlying the extensive smooth and uneroded plains supply large quantities of water to shallow wells. The Dakota sandstone underlies nearly the entire province and provides various areas of artesian flow. Throughout much of the province, however, it lies too far below the surface to be a practical source of water. Where the Tertiary beds are absent or badly eroded and the Dakota sandstone is buried beneath thick beds of shale, as in parts of eastern Colorado, it may be difficult to develop even small water supplies. Many of the valleys contain Quaternary gravels, which supply large quantites of good water. Considerable amounts of Tertiary and Quaternary well water is used for irrigation.

L. Great Plains Pliocene-Paleozoic Province

The principal aquifers of this province are the late Tertiary and Quaternary sands and gravels, which give the same favorable conditions as those in province K. The Tertiary deposits are underlain through practically the entire province by Permain or Triassic "Red Beds", which in most places yield little water or water of high mineral content. In localities where the Tertiary deposits are thin or absent, or where they have been badly eroded, the ground water conditions are generally unfavorable.

M. Trans-Pecos Paleozoic Province

The bedrock consists of Carboniferous and Triassic strata, including shaley cleavage sandstone, and some less shaley cleavage sandstone. In most of the province, these rocks yield only meager supplies of high mineral content from deep wells. In the Pecos Valley, however, Carboniferous limestones and sandstones yield large supplies to numerous flowing wells. The water is very hard, but usable for irrigation, domestic and livestock purposes. The bedrock is locally overlain by Quaternary water-bearing gravels.

N. Northwestern Drift-Eocene-Cretaceous Province

Ground water supplies are obtained from glacial drift and from underlying Eocene and Upper Cretaceous formations. Where the drift is absent or not water bearing, wells are sunk into the underlying formations with variable success. The Eocene and latest Cretaceous formations, which underlie most of the eastern part of the province, generally include strata or lenses of sand, gravel, or coal that yield water. The Cretaceous formations that occur in the western part of the province consist chiefly of alternating beds of shale and sandstone. The sandstones generally yield water, but the shales are unproductive. Where a thicke shale formation immediately underlies glacial drift or is at the surface, it may be difficult to get successful wells. Upland gravels yield water to shallow wells in certain localities.

O. Montana Eocene-Cretaceous Province

Fairly good water in quantities adequate for domestic and livestock supplies and even for small municipal supplies is obtained from strata and lenses of sand, gravel, and coal in the Fort Union (Eocene) and Lance (late

Cretaceous or Eocene) formations which underlie most of the province. These formations usually rest on the Pierre shale, a thick dense shale of Upper Cretaceous age that yields no water or only meager amounts of generally poor quality water. There is great difficulty in obtaining satisfactory water supplies in locations where the Fort Union and Lance formations are absent or do not yield adequately. In the northern part of the province, there is a little water-bearing glacial drift.

P. Southern Rocky Mountain Province

This mountain province is underlain, for the most part, by crystalline rocks. Water supplies are obtained chiefly from springs, from streams fed by springs and melted snow, or from very shallow wells near streams.

Q. Montana-Arizona Plateau Province

This large area is, for the most part, an arid to semi-arid plateau region underlain by sedimentary formations ranging in age from Paleozoic to Tertiary. This area is not violently deformed, but it is sufficiently warped and broken to produce a close relation between rock structure and the occurrence of ground water and to cause rapid variation in ground-water conditions from place to place. On the whole, water supplies are not plentiful and not of very satisfactory quality. Water supplies are scarce where thick formations of nearly impervious material are at the surface, or where the plateau is greatly dissected, as in the Grand Canyon region. Locally, however, sandstone aquifers, such as those of the Kootenai formation, the Dakota sandstone, or the Mesaverde formation, can be developed and may yield very satisfactory supplies - in some places giving rise to flowing wells. There are also local deposits of water-bearing gravels of Quaternary age.

R. Northern Rocky Mountain Province

This region is chiefly mountainous with extensive intermontane valleys and plains. It is underlain by a great variety of rocks with complicated and diverse structures. As in other mountainous regions, water supplies are obtained largely from mountain springs and streams. Considerable water is available in places from valley fill, chiefly ordinary alluvial sand and gravel, and the outwash deposits of mountain glaciers. A few water supplies are also obtained from wells drilled into various rock formations of the

Pre-Cambrian and Tertiary ages.

S. Columbia Plateau Lava Province

The principal aquifers of this province are the widespread Tertiary and Quaternary lava beds and interbedded or associated Tertiary sand and gravel, such as those of the Ellensburg formation. In general, the lava yields abundant supplies of good water. It gives rise to many large springs, especially along the Snake River in Idaho. Locally, the lava or the interbedded sand and gravel may give rise to flowing wells. However, much of the lava is so permeable and the relief of the region is so great that in many places the water table is too far below the surface to be reached except by deep wells. In certain parts of the province, glacial outwash and ordinary valley fill are also important sources of water.

T. Southwestern Bolson Province

The principal source of water supply in this arid province is the alluvial sand and gravel of the valley fill underlying the numerous intermontane valleys that characterize the region. In the elevated marginal parts of the valleys, the water table may be far below the surface or ground water may be absent; in the lowest parts, underlain by clayey and alkaline beds, ground water may be meager in quantity and poor in quality; at intermediate levels, however, large supplies of good water are generally found. Most of the water in the valleys of this province is recovered by pumping wells, but there are many springs and areas of artesian flow. In mountain areas of the province there are many springs, small streams, and shallow wells that furnish valuable supplies. As a rule, the most favorable areas in the mountains for springs and shallow wells are those underlain by granitic rocks.

U. Central Valley of California Province

Ground water of good quality is found chiefly in alluvial cones formed by streams emerging from the Sierra Nevada, although water can be obtained throughout the valley floor. The yield of cones flanking the Coast Range is small, with poorer quality water generally occurring in the south and central sections, and better in the north. Underlying piedmont deposits consist of marine, lacustrine, and alluvial formations. High mineral content connate water is found in deep strata throughout the valley; in the center it occurs near the ground surface. Extensive irrigation in the valley is dependent upon ground water pumped from wells.

V. Coastal Ranges of Central and Southern California Province

The principal ground water bodies are in the mountain valley and plains in the Piedmont Region draining to the Pacific Ocean. Aquifers consist of valley fill and alluvial sand and gravel deposits. Locally, good water supplies are developed from underlying younger Tertiary sandstones. Heavy development of ground water along the coast for municipal and irrigation needs has resulted in sea water entering and contaminating aquifers in several valley mouths.

W. Willamette Valley-Puget Sound Province

A large body of alluvium fills the structural trough forming this province. Abundant supplies of surface water have delayed investigation and exploitation of the extensive ground water resources of the area.

X. Northern Coast Range Province

Ground water is found in the alluvial fill of the valleys draining to the Pacific Ocean. A small area in the southern part of the province contains heated ground water, hot springs, and geysers. Detailed information on ground water conditions is limited because of the abundant surface water and the relatively undeveloped nature of the province.

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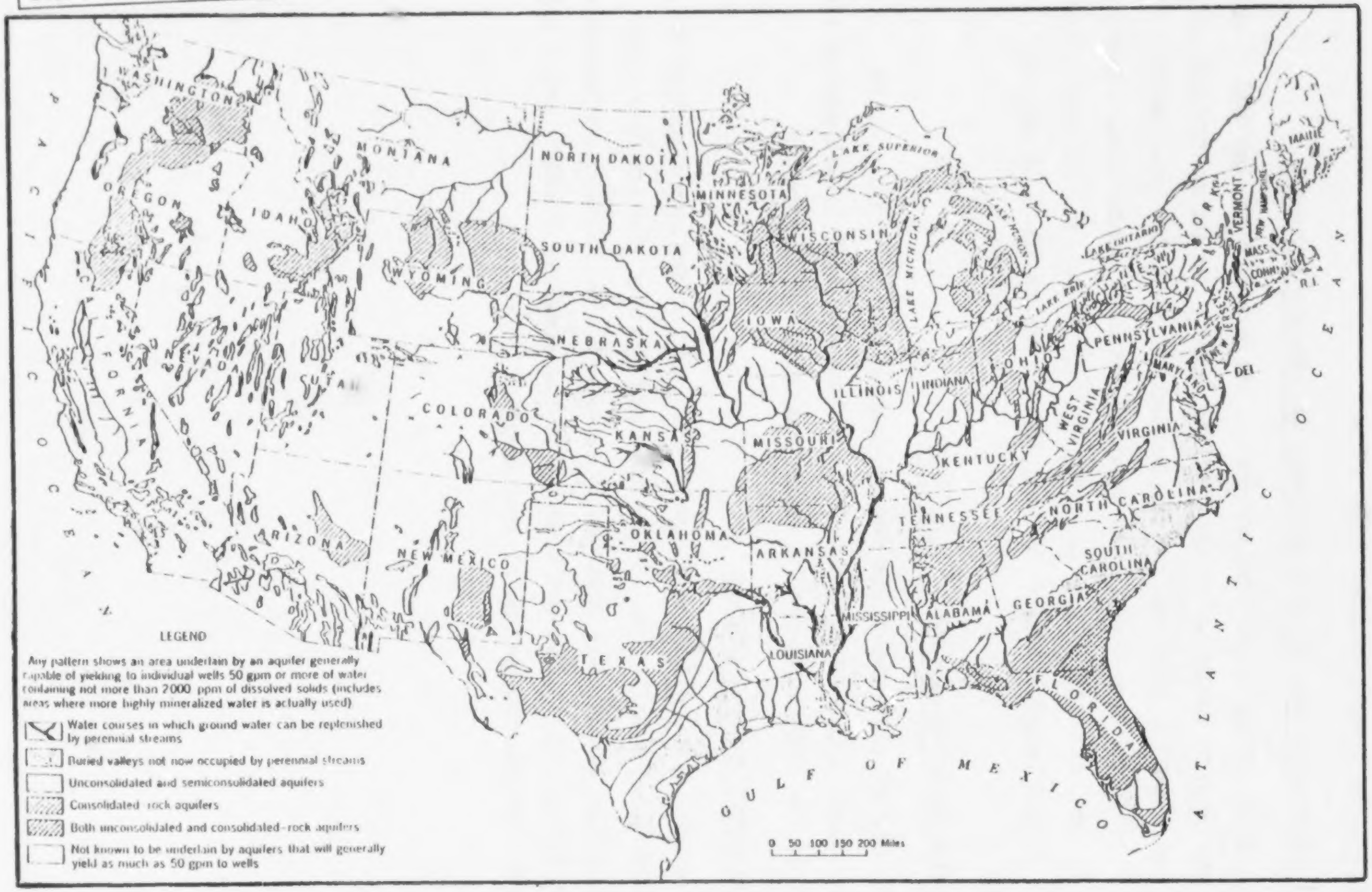
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SOUTH DAKOTA
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Any pattern shows an area underlain by an aquifer generally capable of yielding to individual wells 50 gpm or more of water containing not more than 2000 ppm of dissolved solids (includes areas where more highly mineralized water is actually used)
Water courses in which ground water can be replenished by perennial streams
Buried valleys not now occupied by perennial streams
Unconsolidated and semiconsolidated aquifers
Consolidated rock aquifers
Both unconsolidated and consolidated-rock aquifers
Not known to be underlain by aquifers that will generally yield as much as 50 gpm to wells

Figure A-1. General Distribution of Ground Water Reserves in the U.S.
(Ground water areas from H.E. Thomas, 1951 U.S.G.S. Water Supply Paper 1800)

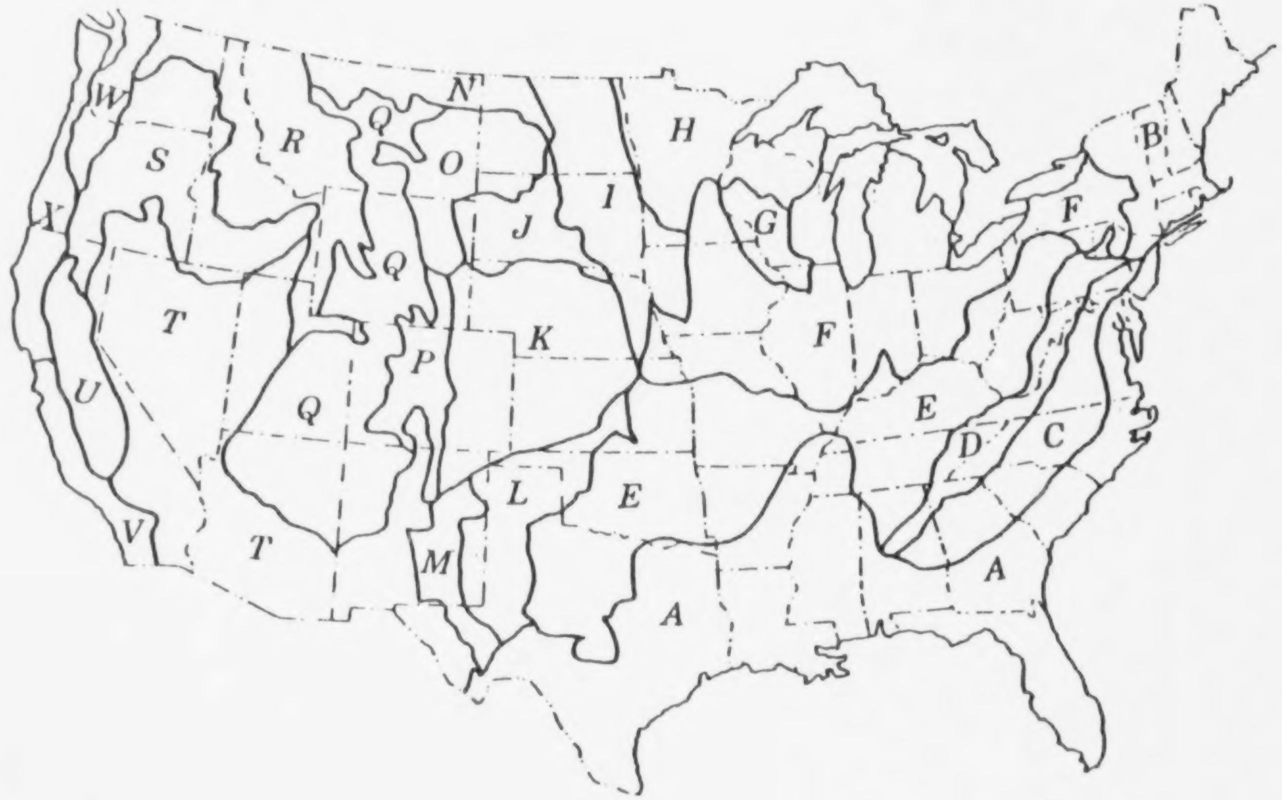
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Figure A-2. U.S.G.S. Ground Water Provinces

(Courtesy of U.S.G.S. Water Supply Paper 836-D)

APPENDIX B

STATE LAWS

State Laws Pertaining to the Protection of Ground Water

The tables in this appendix summarize the results of a state-by-state survey regarding state laws and/or regulations that pertain to the protection of ground water. The provisions, listed below, were established by Versar, Inc. as those that impart effectiveness to a ground water protection regulation. The tables note which of these provisions are included in the state's laws.

Definitions

(1) "Oil or "oils" shall mean oil, including gasoline, crude oil, fuel oil, diesel oil, lubricating oil, sludge, oil refuse and any other petroleum related product.

(2) "Hazardous materials" shall mean any matter of any description or origin other than petroleum related products or radioactive substance which, when discharged into a underground water supply of a state, presents an imminent and substantial hazard to public health, comfort, convenience, efficiency, or esthetics.

(3) "Person" means an individual, partnership, firm, association, joint venture, public or private institution, utility, cooperative, municipality or any other political subdivision of a state.

Provisions

(1) Any person owning or having control over oil or hazardous materials that is spilled such that there is a substantial likelihood it will enter underground public waters shall:

(a) Immediately stop the spilling;

(b) Immediately collect and remove the spilled oil or hazardous material unless not feasible, in which case the person shall take all practicable actions to contain, treat, and disperse the same in a manner acceptable to the state in coordination with the U.S. Environmental Protection Agency and in accordance with Annex X of the National Contingency Plan.

(c) Immediately proceed to correct the cause of the spill;

(d) Immediately notify the state of the type, quantity, and location of the spill, corrective and clean-up actions taken and proposed to be taken; and

(e) Within short duration following a spill, submit a complete written report to the state describing all aspects of the spill and steps taken to prevent a recurrence.

(2) Cleanup of oil or hazardous material spills shall proceed in a timely and diligent manner until official notice is obtained from the state that satisfactory cleanup has been achieved.

(3) State compliance with state abatement requirements does not relieve the owner or person responsible from liabilities, damages or penalties resulting from spill and cleanup of such oil or hazardous materials.

(4) Notification of the state does not relieve the owner or responsible person from the liabilities of the mandatory reporting requirements to the U.S. Environmental Protection Agency.

(5) State cleanup fund for mystery spill.

(6) State underground pipeline and storage tank corrosion requirements.

STATE	TITLE, PERTINENT SECTIONS	PROVISIONS
Alabama	N/A	N/A
Alaska	Alaska Oil Discharge Pollution and Control Act	1-6
Arizona	Arizona Oil Spill Contingency Plan Section A	1d, 2, 4, 5
Arkansas	Water & Air Pollution Control Act	1(a-d) 2, 3, 4
California	Porter-Cologne Act	1-6
Colorado	Colorado Water Quality Control Act Part 6	1d
Connecticut	Water Pollution Laws	1(a-e), 2, 3
Delaware	Delaware Environmental Protection Act Section 6028	1d
Florida	Florida Statutes 403 CH 17 Fla. Rules of Administrative Procedure, Section 3, 4	1(a-e), 2, 4, 5, 6
Georgia	Georgia Water Quality Control Act	1(a-e), 2, 3, 4, 5
Hawaii	Department of Health Regulations Chapter 37-A	1(a-e), 2, 3, 4, 5
Idaho	Water Quality Standards and Wastewater Treatment Requirements Section X G	1a, b, d
Illinois	Illinois Pollution Control Board Rules And Regulations, Chapter 6 Public Water Supplies, 313-C	1a, b, c, d, e 2, 3, 6

STATE	TITLE, PERTINENT SECTIONS	PROVISIONS
Indiana	Indiana Board of Health Regulations	1(a-e), 2, 4, 6
Iowa	Iowa House File 490	1(a-e), 2, 3, 5
Kansas	Kansas Stateboard of Health Regulations 28-16-27. Pollution Spills and By-Passes	1d, e
Kentucky	Water Quality Regulations	1(a-e), 2, 3, 4
Louisiana	Department of Conservation Memorandum	1(a-e), 2, 4
Maine	Oil Conveyance Law, MRSA Title 38, Chap. 3, Oil Discharge Prevention & Pollution Controls	1(a-e), 2, 3, 5, 6 (oil only)
Maryland	Maryland Natural Resources Law For Hazardous Substance	1(a-e), 2, 3, 5
Massachusetts	General Laws of Massachusetts	1(a-d), 2, 3, 4, 5, 6
Michigan	Michigan Spills Contingency Plan	1(a-e), 2
Minnesota	Laws Relating to the Minnesota Pollution Control Agency, Chapter 116, Section 116.061	1a, b, c, d
Mississippi	Mississippi Code Of 1972, Section 49, 17.1 - 17.31	1(a-d), 2, 3, 5
Missouri	Rules of Department of Natural Resources Division 20 - Clean Water Commission Chapter 5 - Hazardous Materials 10 CSR 20-5.010	1a, d, 2
Montana	N/A	N/A

STATE	TITLE, PERTINENT SECTIONS	PROVISIONS
Nebraska	Groundwater Standards	1(a-e), 2, 4
Nevada	State of Nevada Water Pollution Controls	1(a-e), 2, 3, 4, 5
New Hampshire	New Hampshire Revised Statutes Chapter 146-A	1(a-d), 2, 3, 4
New Jersey	Spill Contingency & Control Act	1(a-e), 2, 3, 4, 5
New Mexico	Amended Water Quality Control Commission Regulations 1-203 Notification of Discharge	1a, b, d
New York •	Policies and Procedures Manual Title 1800 - Emergency Operations New York State Department of Environmental Conservation (Memorandum)	1d, 4 6
North Carolina		
North Dakota	Spill Contingency Plan	1(a-e), 2, 3, 4
Ohio	Ohio Water Pollution Controls	2
Oklahoma	Oklahoma Statute 52	1(a-d), 2, 3
Oregon	Oregon Department of Environmental Quality, Oil Spill Contingency Plan Subdivision 7, 47-105 Notice, Control and CleanUp of Oil Spills Req.	1a, b, c, d, e, 2, 3
Pennsylvania	Title 25 Rules and Regulations Part I. Department of Environmental Resources Subpart C Protection of Natural Resources Article II. Water Resources 101.2	1(a-d), 2, 3, 4, 5

STATE	TITLE, PERTINENT SECTIONS	PROVISIONS
Rhode Island	General Laws of Rhode Island	1(a-c), 4
South Carolina	Federal Water Pollution Control Act. PL-92-500	1(a-e), 2, 3, 4
South Dakota	South Dakota Water Pollution Standards	1a, b, d, e, 3
Tennessee	Tennessee Code Anotated	1(a-d), 2, 3
Texas	State of Texas Oil and Hazardous Pollution Contingency Plan Section VI	1d, 2, 3, 4
Utah	State of Utah Oil and Hazardous Spills Directory	1a, b, d
Vermont	Vermont Statutes Annotated, Chapter 47 Section 12	1(a-d), 2, 3, 4
Virginia	State Water Control Law Article 8	3
Washington	Laws and Oil Spill Emergency Procedures	1a, b, d, 3
West Virginia	Code of West Virginia Chap. 20, Article 5A	1(a-e), 2, 3, 4
Wisconsin	Wisconsin Proposed Bill 880	1a, b, c, d
Wyoming	Wyoming Water Quality Rules and Regulations Chapter IV	1-6

APPENDIX C

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Alaska	Coast Guard Juneau	800-442-8802
Arizona	Bureau of Health Services	602-255-1173
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California	Emergency Services	800-852-7550
Colorado	Department of Health	303-388-6111 x231 303-366-5363 (after hours)
Connecticut	State Environmental Protection Agency	203-566-3338
Delaware	Natural Resources and Environmental Control	302-678-4761
Florida	Department of Environmental Regulations	904-487-1980
Georgia	Environmental Protection Division	404-656-4300
Hawaii	Coast Guard	800-442-8802
Idaho	Department of Health and Welfare	208-384-2433
Illinois	State Environmental Protection Agency	217-782-3637
Indiana	Department of Health	317-633-1709
Iowa	Department of Environmental Quality	515-281-8931
Kansas	Department of Health	913-862-9360
Kentucky	Department of Natural Resources and Environmental Protection	502-564-3410
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New Hampshire	Water Supply & Pollution Control Commission	603-271-3303
New Jersey	Department of Environmental Protection	609-292-7172
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Rhode Island	Department of Health	401-277-2234
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Vermont	Department of Water Resources	802-828-2763
Virginia	Water Control Board	804-786-2241
Washington	Department of Ecology	206-753-2353
West Virginia	Department of Natural Resources	304-348-2107
Wisconsin	Department of Natural Resources	608-266-2857
Wyoming	Department of Environmental Quality	307-777-7781
District of Columbia	Department of Environmental Services	202-767-7370 202-629-4522 (after hours)

Coast Guard Chemical Hazards Response Information System	800-442-8802
Interagency Radiological Assistance Plan	800-424-9300
Coast National Strike Force	800-424-8802
U.S. Army Technical Escort Center Chemical Emergency Response Team	703-521-2185
Pesticides Safety Team Network	800-424-9300
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APPENDIX D

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APPENDIX E

A MANUAL FOR EVALUATING CONTAMINATION POTENTIAL OF SURFACE IMPOUNDMENTS

A MANUAL FOR
EVALUATING CONTAMINATION POTENTIAL
OF SURFACE IMPOUNDMENTS

This manual was written

by

Lyle R. Silka and Ted L. Swearingen

Ground Water Protection Branch
Office of Drinking Water
U.S. Environmental Protection Agency

June 1978

DISCLAIMER

This manual has been reviewed by the Office of Drinking Water, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the official ground-water protection policy of the U.S. Environmental Protection Agency.

PREFACE

The Manual for Evaluating Contamination Potential of Surface Impoundments was prepared specifically for implementing a standardized evaluation system for the EPA Office of Drinking Water Surface Impoundment Assessment (SIA) and serves as the training manual for that assessment. The SIA evaluation system set forth in the manual is based upon the previous work by Harry E. LeGrand who began over 15 years ago to develop a standardized, consistent approach to the selection of proper waste disposal sites. This system departs from the LeGrand system in order to accommodate certain philosophical differences concerning ground-water protection and specific technical aspects related to surface impoundments. In no way does this detract from the importance of the LeGrand system in serving as the basis for the SIA evaluation system.

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INTRODUCTION

An objective of the surface impoundment assessment (SIA) program (see Figure 1) is to rate the contamination potential of ground water from surface impoundments and to develop practices for the evaluation of different surface impoundments (elsewhere referred to as pits, ponds, and lagoons). One of the activities conducted under the SIA program is the application of the evaluation system described in the present manual. This evaluation system applies a numerical rating scheme to different impoundments that yields a first round approximation of the relative ground-water contamination potential of these impoundments.

The basis of this system was developed by Harry E. LeGrand in 1964. LeGrand and Henry S. Brown expanded and improved the system in 1977 under contract to the Office of Drinking Water. The present system described in this manual has been modified by the Office of Drinking Water through consultation with LeGrand and Brown to reflect its ground-water protection philosophy. Before the selection of the present evaluation system, other standardized systems were considered (Cherry, et. al., 1975; Pinder, et. al., 1977; Phillips, 1976) but were not deemed as suitable for the purposes of the assessment. The system is designed to provide an

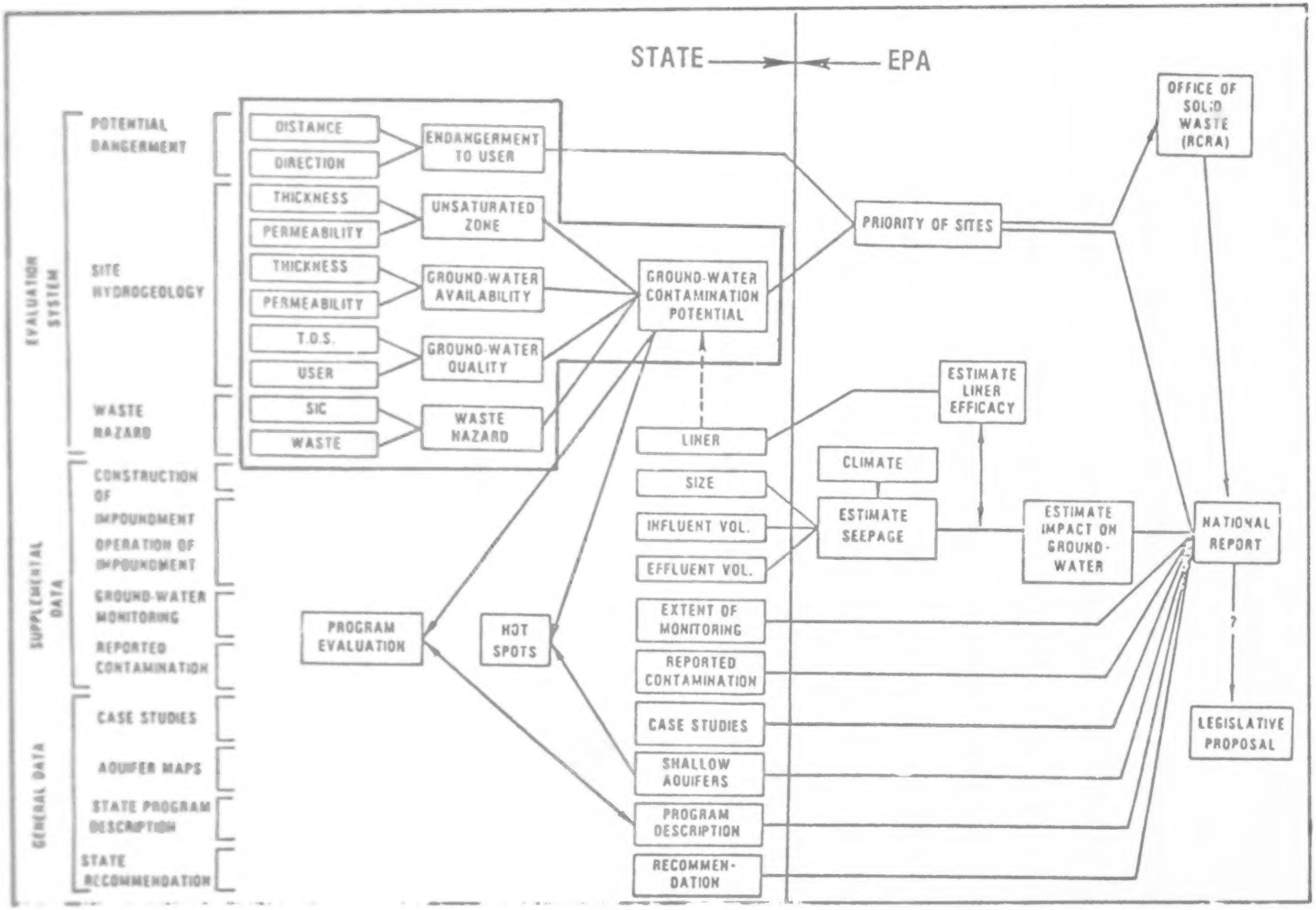
STATE
EPA
EVALUATION SYSTEM
POTENTIAL DANGERMENT
SITE HYDROGEOLOGY
WASTE HAZARD
SUPPLEMENTAL DATA
CONSTRUCTION OF IMPOUNDMENT
OPERATION OF IMPOUNDMENT
GROUND-WATER MONITORING
REPORTED CONTAMINATION
GENERAL DATA
CASE STUDIES
AQUIFER MAPS
STATE PROGRAM DESCRIPTION
STATE RECOMMENDATION
DISTANCE
DIRECTION
THICKNESS
PERMEABILITY
THICKNESS
PERMEABILITY
T.D.S.
USER
SIC
WASTE
ENDANGERMENT TO USER
UNSATURATED ZONE
GROUND-WATER AVAILABILITY
GROUND-WATER QUALITY
WASTE HAZARD
GROUND-WATER CONTAMINATION POTENTIAL
LINER
SIZE
INFLUENT VOL.
EFFLUENT VOL.
EXTENT OF MONITORING
REPORTED CONTAMINATION
CASE STUDIES
SHALLOW AQUIFERS
PROGRAM DESCRIPTION
RECOMMEN-DATION
PROGRAM EVALUATION
HOT SPOTS
PRIORITY OF SITES
ESTIMATE LINER EFFICACY
CLIMATE
ESTIMATE SEEPAGE
ESTIMATE IMPACT ON GROUND-WATER
OFFICE OF SOLID WASTE (RCRA)
NATIONAL REPORT
?
LEGISLATIVE PROPOSAL

Figure 1. Flow chart of the Surface Impoundment Assessment. The outlined portion is the evaluation system described in this manual.

approximation of the ground-water contamination potential of impoundments at a minimum cost. Precise, in-depth investigations of actual ground-water contamination from surface impoundments (i. e., drilling, etc.) would be too costly and time-consuming and are not involved in this first-round site evaluation. The specific site investigations into actual contamination would begin after this assessment is finished in order to optimize expenditures. Those sites identified as high contamination potential would be addressed first.

The philosophy guiding the development of this surface impoundment evaluation system is that underground drinking water sources must be protected for both present and future users as intended by Congress in the Safe Drinking Water Act, 1974. Ground-water pollution occurs when contaminants reach the water table (saturated zone) beneath the site. This is contrary to the commonly held view that ground-water contamination cannot legally be determined until the contaminated ground water crosses the property boundaries of the facilities. EPA believes that in order to protect the nation's ground-water resources it is necessary to identify potential contamination at the source where preventive measures may be initiated. The purpose of this evaluation system is to rank impoundments in terms of their relative ground-water contamination potential. The evaluation system considers several hydrogeologic parameters in the rating of the site. There are numerous parameters that may be used in evaluating a site. However, many of these parameters are related and their simultaneous consideration would be redundant. Thus, only selected parameters representative of different processes, have been included. The present evaluation system provides a standardized methodology which will ensure more consistent national results.

The parameters used in the present SIA system have been separated into two distinct groups which correspond to the two phases of the evaluation, i. e., 1) the rating of the ground water contamination potential itself and 2) the rating of the relative magnitude of potential endangerment to current users of underground drinking water sources. The parameters considered unique in rating the ground-water contamination potential are 1) the thickness of the unsaturated zone and the type of earth material of that zone, 2) the relative hazard of the waste, and 3) the quantity and quality of the underground drinking water source beneath the site. The parameters considered unique in determining the rating for the potential for endangerment of currently used water resources include: 1) the type of water source, i. e. ground water or surface water, 2) whether that water source is in the anticipated flow direction of the contaminated ground water (if such contamination occurred); and 3) the distance between the potential contamination source and the water source. These parameters account for the basic processes and factors which determine the contamination potential of the site and which indicated the relative threat to underground drinking water sources.

The level of contamination of ground water is subject to varying degrees of attenuation as the water flows through the unsaturated zone and on through the aquifer; however, the evaluation focuses on the potential for contamination of underground water sources. Attenuation mechanisms are very complex, varying with the type of waste, earth material, and physico-chemical environment. A general site evaluation system concerned with an approximation of the contamination potential cannot consider the specific attenuative capabilities of different earth materials for different wastes, particularly since there exists a vast variety of complex wastes possible. This evaluation system therefore treats attenuation in an indirect manner by considering it in combination with permeability.

The evaluation is performed in a sequence (see Figure 2). The first four steps involve the evaluation of the potential for ground water to be contaminated by rating the site's hydrogeology and waste character. The fifth step then determines the site's overall contamination potential relative to other rated sites by combining the first four steps. It must be stressed that this overall rating will express only a site's hydrogeologic

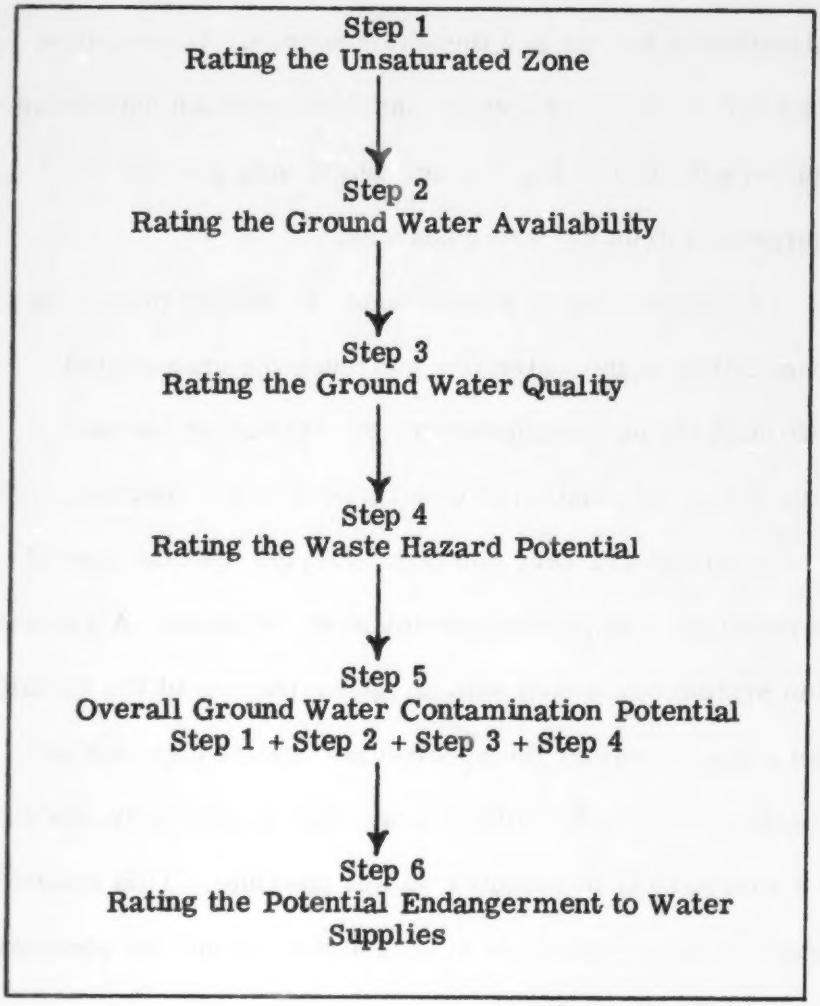
Step 1
Rating the Unsaturated Zone
Step 2
Rating the Ground Water Availability
Step 3
Rating the Ground Water Quality
Step 4
Rating the Waste Hazard Potential
Step 5
Overall Ground Water Contamination Potential
Step 1 + Step 2 + Step 3 + Step 4
Step 6
Rating the Potential Endangerment to Water Supplies

Figure 2. Generalized sequence of steps involved in the SIA evaluation system.

conditions relative to those conditions for all possible sites, and does not relate to a site's absolute degree of ground-water contamination. Such determination of actual contamination involving ground-water monitoring and sampling procedures must be made following site specific investigations. This system allows the investigator to assign priorities to sites on the basis of contamination potential so that the investigator could then concentrate resources upon the further investigation of these sites that rank highest in terms of their contamination potential.

Precise data is not necessary for the application of the SIA evaluation system. Performing precise measurements of the the depth to the water table, the character of the earth materials underlying the site, the hydrogeology at the site, etc., can be costly and time consuming. It must be remembered that this evaluation system is a first-round approximation and therefore estimates based on the best available information will be used with the expectation that they will provide satisfactory results for first-round evaluations.

STEP 1

GUIDANCE FOR RATING THE UNSATURATED ZONE

The earth material characteristics of the unsaturated zone underlying the surface impoundment are rated to determine the potential for contaminants to reach the water table. This step involves the combined rating of a) the thickness of the unsaturated zone, and b) earth material (both consolidated and unconsolidated rock) in the unsaturated zone (see Table I).

Step 1, Part A, Determination of the depth to the saturated zone for Step 1

Contaminants attenuate to varying degrees as they migrate down through the unsaturated zone, depending upon the thickness and the type of earth material. Therefore, more favorable conditions exist where the water table is deeper. The depth to the saturated zone is the depth from the base of the surface impoundment to the water table. This depth may be measured to the water table in unconfined aquifers (See Site 1 in Figure 3) or, in the case of a confined aquifer, to the top of the confined aquifer (See Site 2 in Figure 3). Where a perched water table is known to occur, the depth may be measured

TABLE I

Step 1. Rating of the Unsaturated Zone.

GUIDELINES FOR DETERMINING CATEGORY

Earth Material Category	I	II	III	IV	V	VI
Unconsolidated Rock	Gravel, Medium to Coarse Sand	Fine to Very Fine Sand	Sand with < 15% clay, Silt	Sand with > 15% but ≤ 50% clay	Clay with < 50% sand	Clay
Consolidated Rock	Cavernous or Fractured Limestone, Evaporites, Basalt Lava Fault Zones	Fractured Igneous and Metamorphic (Except Lava) Sandstone (Poorly Cemented)	Sandstone (Moderately Cemented) Fractured Shale	Sandstone (Well Cemented)	Siltstone	Unfractured Shale, Igneous and Metamorphic Rocks
Representative Permeability in gpd/ft^2 - in cm/sec -	 > 200 $> 10^{-2}$	 $2 - 200$ $10^{-4} - 10^{-2}$	 $0.2 - 2$ $10^{-5} - 10^{-4}$	 < 0.2 $< 10^{-5}$	 < 0.02 $< 10^{-6}$	 < 0.002 $< 10^{-7}$
RATING MATRIX						
Thickness of the Unsaturated Zone (in Meters)						
> 30	9A	6B	4C	2D	0E	0F
$> 10 \leq 30$	9B	7B	5C	3D	1E	0G
$> 3 \leq 10$	9C	8B	6C	4D	2E	0H
$> 1 \leq 3$	9D	9F	7C	5D	3E	1F
$> 0 \leq 1$	9E	9G	9H	9I	9J	9K

to it rather than the underlying regional water table (See Site 3 in Figure 3). The investigator will decide whether to measure the depth to the perched water table or ignore it and measure to the regional water table. This decision should be based on the extent and thickness of the perched water table and its usefulness as a drinking water source. If the perched water table is currently being utilized as a drinking water source, the depth should be measured to it.

Water tables fluctuate on a diurnal, seasonal and annual basis due to natural and artificial causes. For this assessment system the depth to the water table should be determined on the basis of the seasonal high water table elevation. As is shown in Table I, the depth determination does not have to be exact since the intervals are large. Illustrations of possible well hydrographs are shown in Figures 4 and 5. Figure 4a depicts a hydrograph of a well in Illinois which is only affected by seasonal climatic variation. The depth to water table would be taken as approximately five feet (1.6 meters). In Figure 4b the well hydrograph illustrates a water table which is affected by seasonal pumping variation. Pumping is greatest and, as a result, the water table is lowest during May through September, the hot season when consumption

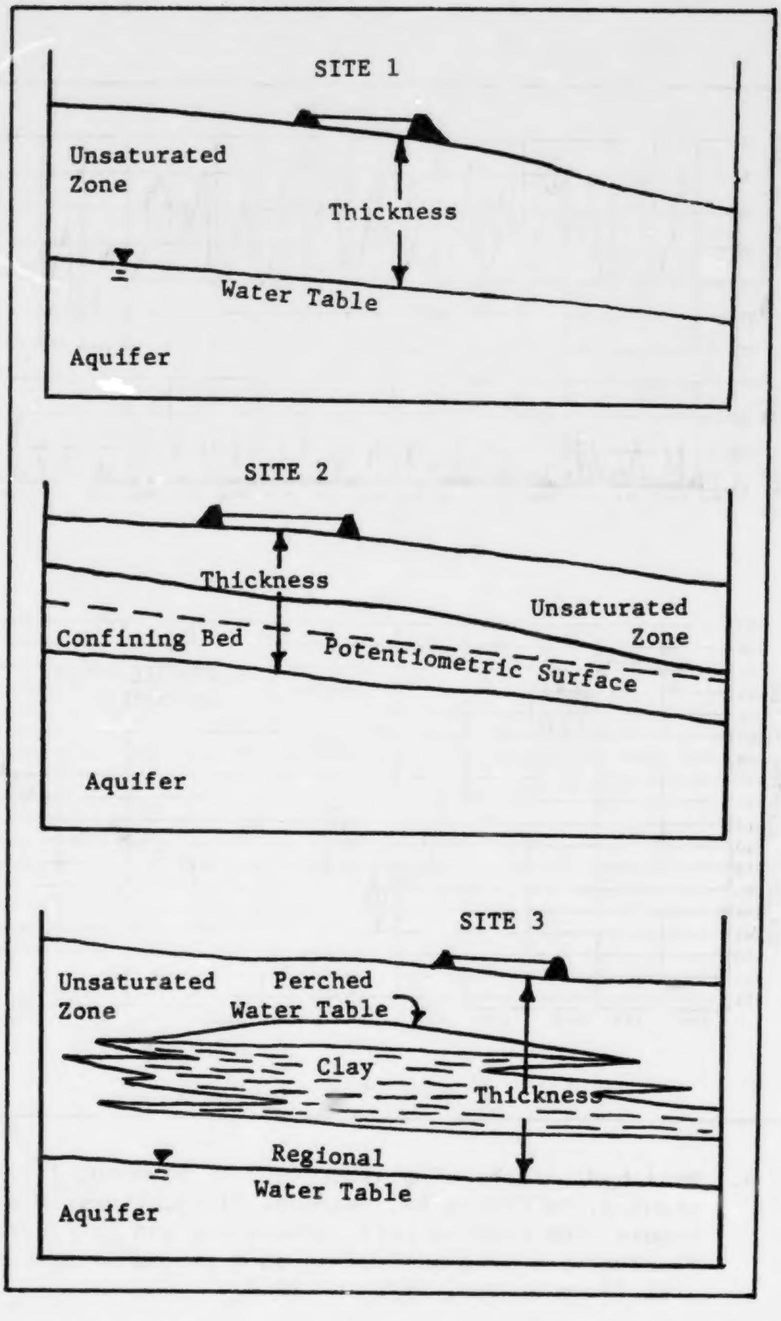
SITE 1
Unsaturated Zone
Thickness
Water Table
Aquifer
SITE 2
Thickness
Unsaturated Zone
Confining Bed
Potentiometric Surface
Aquifer
SITE 3
Unsaturated Zone
Perched Water Table
Clay
Thickness
Regional Water Table
Aquifer

Figure 3. Guide for the determination of the depth to the saturated zone (water table in the unconfined case or top of confined aquifer) for completion of Step 1.

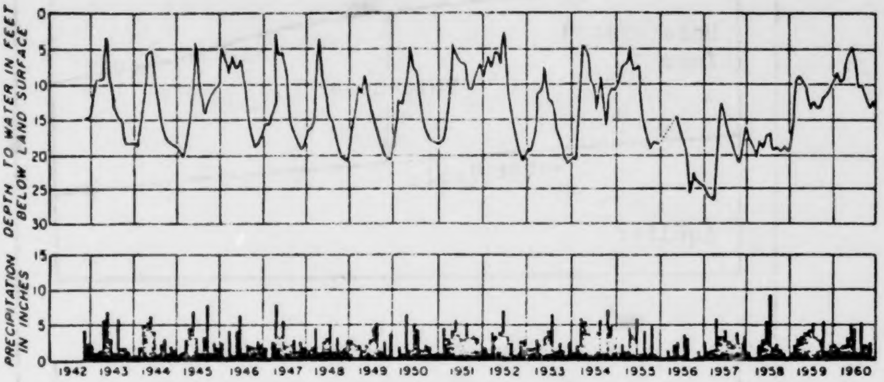

Figure 4A

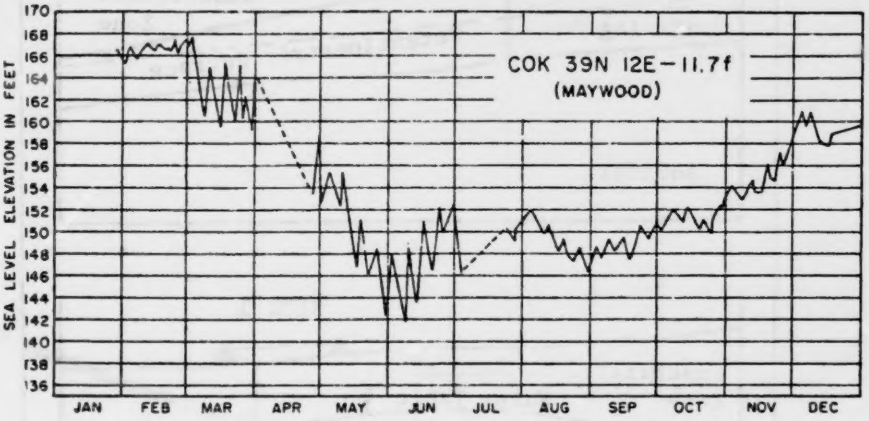

Figure 4B

Figure 4. Well hydrographs of a water well at Maywood, Illinois, showing, in Figure 4A, seasonal fluctuations in a well remote from pumping well influences; and in Figure 4B, fluctuations in a well close to a ground water pumping area (from Walton, 1970, p. 106).

is greatest. During the winter months of November through March the demand decreases and the ground-water table recovers. In this case the depth to the water table would be computed at the highest level, at 168 feet (51.2 meters) of elevation rather than the summer levels of 142 feet (43.3 meters).

Figure 5 shows a long period of record for a well hydrograph located in Ainsworth, Nebraska, in which annual and longer term fluctuations exist. Although the maximum change in water level amounts to only about 6 or 7 feet (2 meters), other areas of the country do experience much greater variation and should be considered. However, in this example, the water level used in determining the depth to the water table should be the higher level of 34 feet (10.4 meters) below the surface. Note that in all these examples, the more conservative estimate is used for depth to the water table.

In the situation where a confined (artesian) aquifer is encountered below a disposal site and an unconfined (water table) aquifer does not exist, the depth is measured to the top of that confined aquifer. Due to the nature of the confined aquifer, the net hydrostatic head of the system may decrease the possibility of contamination. However, conditions are not steady-state and other phenomena may affect the

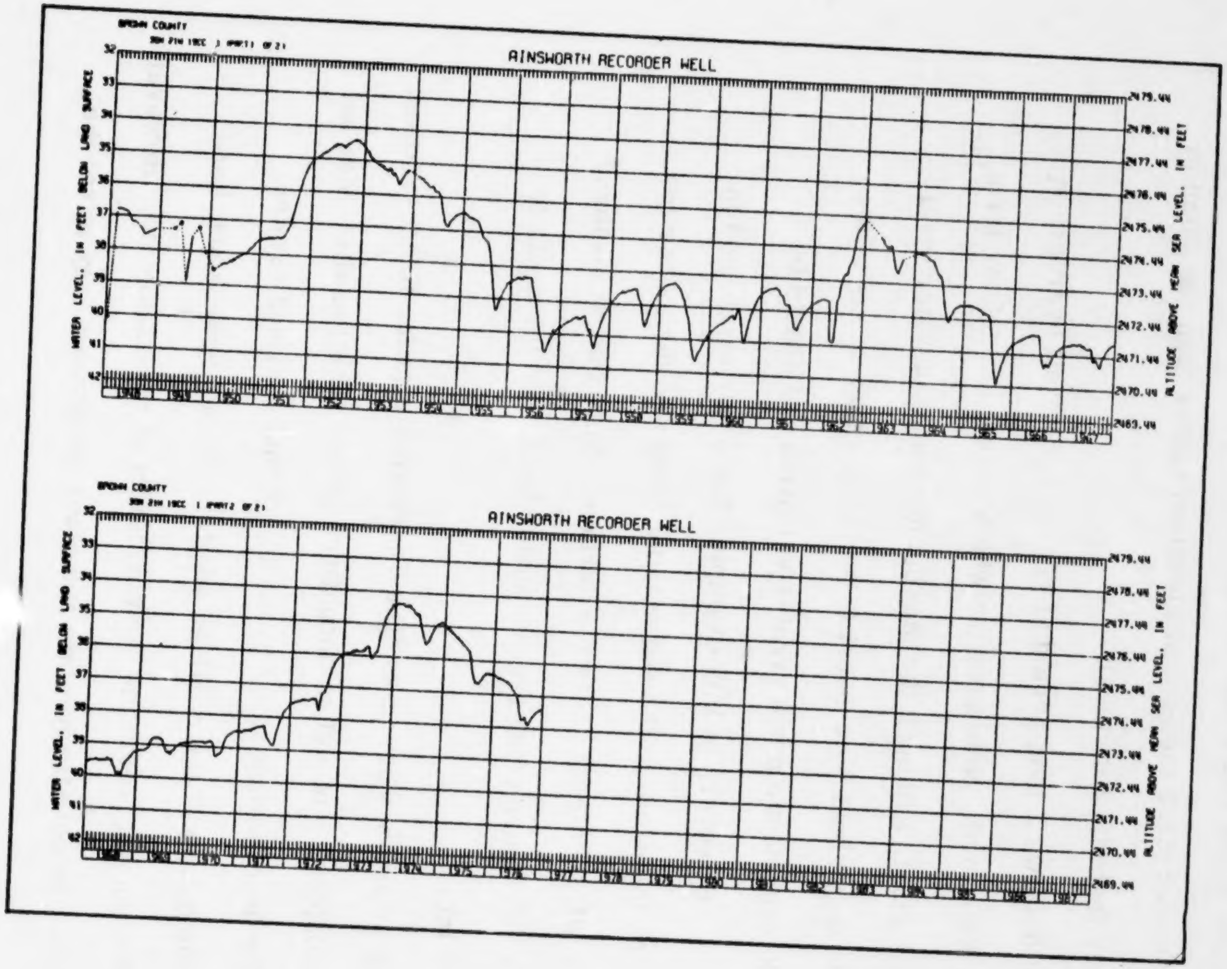

Figure 5. Well hydrograph of the Ainsworth, Nebraska, water supply well showing annual and longer term ground water level fluctuations (from Ellis and Pederson, 1977, p. 67).

net hydrostatic head of the confined aquifer. With the reductions of head which can be experienced (as in many irrigated areas of the country), confined aquifers may become vulnerable to contamination from surface sources through over pumping.

Step 1, Part B, Determination of the earth material category for Step 1

The type of earth material must be identified in order to complete Step 1. Table I contains an ordinal ranking of the general categories of earth materials based upon permeability, secondarily upon sorption character. The inclusion of sorption is based on the general relationships between grain size/surface area and permeability/sorption. Grain size (or pore size) is proportional to permeability and inversely proportional to surface area which is an important factor in sorption mechanisms. As grain size is inversely proportional to sorption capacity, sorption capacity is inversely proportional to permeability. Thus, going from left to right across the earth material categories in Table I, permeability decreases while sorption generally tends to increase. The categories take into account whether the permeability of the material is primary (properties existing at the time of formation such as the pore spaces) or secondary (properties of the material imposed upon it sometime after formation such as joints, fractures, faults and solution channels). Secondary permeability is usually much greater than primary permeability due to the larger pathways. This distinction is very important in the categorization of earth materials as the presence of secondary permeability increases the flow of water and decreases attenuation. Fractures, joints, and faults are caused by earth movement and generally become closed and tighter with depth (generally within a hundred meters) because of increased pressures and decreased weathering effects. Faults often have an associated zone of crushed rock (fault breccia) which may be highly permeable.

The classification of the earth material should follow the guidelines of Table I and of Figures 6 and 7 which supply further assistance in the classification. Figure 6 gives a fairly comprehensive list of driller's terms found in driller's logs and the equivalent classification for Table I. Some groups of terms are assigned to more than one category, in which case the investigator must make a judgement. In Figure 7, the equivalent Unified Soil Classification System codes are shown.

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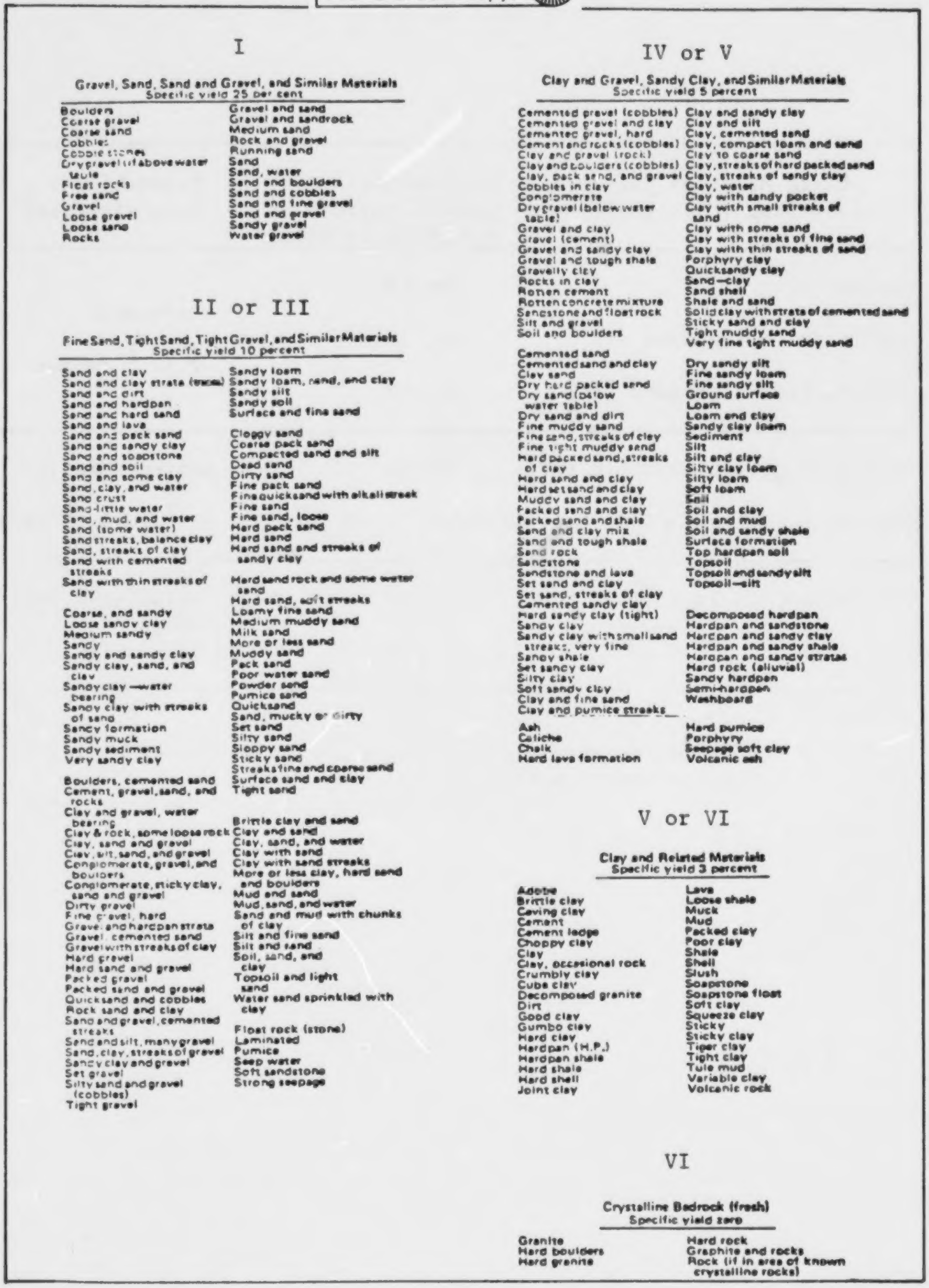


I

Gravel, Sand, Sand and Gravel, and Similar Materials
Specific yield 25 per cent

Boulders
Coarse gravel
Coarse sand
Cobbles
Cobble stones
Dry gravel (if above water table)
Float rocks
Free sand
Gravel
Loose gravel
Loose sand
Rocks

Gravel and sand
Gravel and sandrock
Medium sand
Rock and gravel
Running sand
Sand
Sand, water
Sand and boulders
Sand and cobbles
Sand and fine gravel
Sand and gravel
Sandy gravel
Water gravel

II or III

Fine Sand, Tight Sand, Tight Gravel, and Similar Materials
Specific yield 10 percent

Sand and clay
Sand and clay strata (tacos)
Sand and dirt
Sand and hardpan
Sand and hard sand
Sand and lava
Sand and pack sand
Sand and sandy clay
Sand and soapstone
Sand and soil
Sand and some clay
Sand, clay, and water
Sand crust
Sand-little water
Sand, mud, and water
Sand (some water)
Sand streaks, balance clay
Sand, streaks of clay
Sand with cemented streaks
Sand with thin streaks of clay

Coarse, and sandy
Loose sandy clay
Medium sandy
Sandy
Sandy and sandy clay
Sandy clay, sand, and clay
Sandy clay —water bearing
Sandy clay with streaks of sand
Sandy formation
Sandy muck
Sandy sediment
Very sandy clay

Boulders, cemented sand
Cement, gravel, sand, and rocks
Clay and gravel, water bearing
Clay & rock, some loose rock
Clay, sand and gravel
Clay, silt, sand, and gravel
Conglomerate, gravel, and boulders
Conglomerate, sticky clay, sand and gravel
Dirty gravel
Fine gravel, hard
Gravel and hardpan strata
Gravel, cemented sand
Gravel with streaks of clay
Hard gravel
Hard sand and gravel
Packed gravel
Packed sand and gravel
Quicksand and cobbles
Rock sand and clay
Sand and gravel, cemented streaks
Sand and silt, many gravel
Sand, clay, streaks of gravel
Sandy clay and gravel
Set gravel
Silty sand and gravel (cobbles)
Tight gravel

Sandy loam
Sandy loam, sand, and clay
Sandy silt
Sandy soil
Surface and fine sand

Cloggy sand
Coarse pack sand
Compacted sand and silt
Dead sand
Dirty sand
Fine pack sand
Fine quicksand with alkali streak
Fine sand
Fine sand, loose
Hard pack sand
Hard sand
Hard sand and streaks of sandy clay

Hard sand rock and some water sand
Hard sand, soft streaks
Loamy fine sand
Medium muddy sand
Milk sand
More or less sand
Muddy sand
Pack sand
Poor water sand
Powder sand
Pumice sand
Quicksand
Sand, mucky or dirty
Set sand
Silty sand
Sloppy sand
Sticky sand
Streaks fine and coarse sand
Surface sand and clay
Tight sand

Brittle clay and sand
Clay and sand
Clay, sand, and water
Clay with sand
Clay with sand streaks
More or less clay, hard sand and boulders
Mud and sand
Mud, sand, and water
Sand and mud with chunks of clay
Silt and fine sand
Silt and sand
Soil, sand, and clay
Topsoil and light sand
Water sand sprinkled with clay

Float rock (stone)
Laminated
Pumice
Seep water
Soft sandstone
Strong seepage

IV or V

Clay and Gravel, Sandy Clay, and Similar Materials
Specific yield 5 percent

Cemented gravel (cobbles)
Cemented gravel and clay
Cemented gravel, hard
Cement and rocks (cobbles)
Clay and gravel (rock)
Clay and boulders (cobbles)
Clay, pack sand, and gravel
Cobbles in clay
Conglomerate
Dry gravel (below water table)
Gravel and clay
Gravel (cement)
Gravel and sandy clay
Gravel and tough shale
Gravelly clay
Rocks in clay
Rotten cement
Rotten concrete mixture
Sandstone and float rock
Silt and gravel
Soil and boulders

Cemented sand
Cemented sand and clay
Clay sand
Dry hard packed sand
Dry sand (below water table)
Dry sand and dirt
Fine muddy sand
Fine sand, streaks of clay
Fine tight muddy sand
Hard packed sand, streaks of clay
Hard sand and clay
Hard set sand and clay
Muddy sand and clay
Packed sand and clay
Packed sand and shale
Sand and clay mix
Sand and tough shale
Sand rock
Sandstone
Sandstone and lava
Set sand and clay
Set sand, streaks of clay
Cemented sandy clay
Hard sandy clay (tight)
Sandy clay
Sandy clay with small sand streaks, very fine
Sandy shale
Set sandy clay
Silty clay
Soft sandy clay
Clay and fine sand
Clay and pumice streaks

Ash
Caliche
Chalk
Hard lava formation

Clay and sandy clay
Clay and silt
Clay, cemented sand
Clay, compact loam and sand
Clay to coarse sand
Clay, streaks of hard packed sand
Clay, streaks of sandy clay
Clay, water
Clay with sandy pocket
Clay with small streaks of sand
Clay with some sand
Clay with streaks of fine sand
Clay with thin streaks of sand
Porphyry clay
Quicksandy clay
Sand—clay
Sand shell
Shale and sand
Solid clay with strata of cemented sand
Sticky sand and clay
Tight muddy sand
Very fine tight muddy sand

Dry sandy silt
Fine sandy loam
Fine sandy silt
Ground surface
Loam
Loam and clay
Sandy clay loam
Sediment
Silt
Silt and clay
Silty clay loam
Silty loam
Soft loam
Soil
Soil and clay
Soil and mud
Soil and sandy shale
Surface formation
Top hardpan soil
Topsoil
Topsoil and sandy silt
Topsoil—silt

Decomposed hardpan
Hardpan and sandstone
Hardpan and sandy clay
Hardpan and sandy shale
Hardpan and sandy stratas
Hard rock (alluvial)
Sandy hardpan
Semi-hardpan
Washboard

Hard pumice
Porphyry
Seepage soft clay
Volcanic ash

V or VI

Clay and Related Materials
Specific yield 3 percent

Adobe
Brittle clay
Caving clay
Cement
Cement ledge
Choppy clay
Clay
Clay, occasional rock
Crumbly clay
Cube clay
Decomposed granite
Dirt
Good clay
Gumbo clay
Hard clay
Hardpan (H.P.)
Hardpan shale
Hard shale
Hard shell
Joint clay

Lava
Loose shale
Muck
Mud
Packed clay
Poor clay
Shale
Shell
Slush
Soapstone
Soapstone float
Soft clay
Squeeze clay
Sticky
Sticky clay
Tiger clay
Tight clay
Tule mud
Variable clay
Volcanic rock

VI

Crystalline Bedrock (fresh)
Specific yield zero

Granite
Hard boulders
Hard granite

Hard rock
Graphite and rocks
Rock (if in area of known crystalline rocks)

Figure 6. Common driller's terms used in estimating specific yield (from Todd, 1970, p. 205) and the equivalent evaluation system earth material categories.

Step 1 Earth Material Category (and Step 1 Designation)	Unified Soil Classification System Designation	Permeability Range (cm/sec)
Gravel (I)	GW, GP	Permeable $> 10^{-4}$ cm/sec
Medium to Coarse Sand (I)	SW, SP	
Fine to Very Fine Sand (II)	SW, SP	
Sand with $\leq 15\%$ Clay, Silt (III)	GM, SM, SC	Semi-permeable 10^{-2} to 10^{-6} cm/sec
Sand with $> 15\%$ but $\leq 50\%$ Clay (IV)	GM, SM, ML	
Clay with $< 50\%$ Sand (V)	OL, MH	Relatively impermeable $< 10^{-6}$ cm/sec
Clay (VI)	CL, CH, OH	

Figure 7. Earth material categories and their approximate Unified Soil Classification System equivalents.

The geologic conditions beneath the site can be a very complex layering of clays, sands and gravels or consolidated sedimentary rocks such as sandstone, limestone and shale. In these layered situations the rating may be accomplished by considering the probable hydrology of the system. Where the different layers have similar hydrologic properties, the layers may be considered a single hydrologic unit for rating purposes. Where contrasting layers are encountered, best judgement must be exercised in rating the site. For example, if an impermeable shale overlies permeable sandstone rate only the thickness of shale. The investigator must be cautioned, however, that in rating a case where hydrologically unlike layers alternate, the waste is more likely to move through the more permeable zones and avoid the impermeable layers. As an example, a sand containing clay lenses should be rated as if only sand were present (See Figure 8). Similarly, where secondary permeability is present (i. e. fractures, joints and faults) the major path of waste movement is through the large conduits of secondary permeability rather than the interstices of primary permeability. This results in a short circuit of any attenuation capability present in the material. In such cases, the earth material would be rated as the more permeable categories.

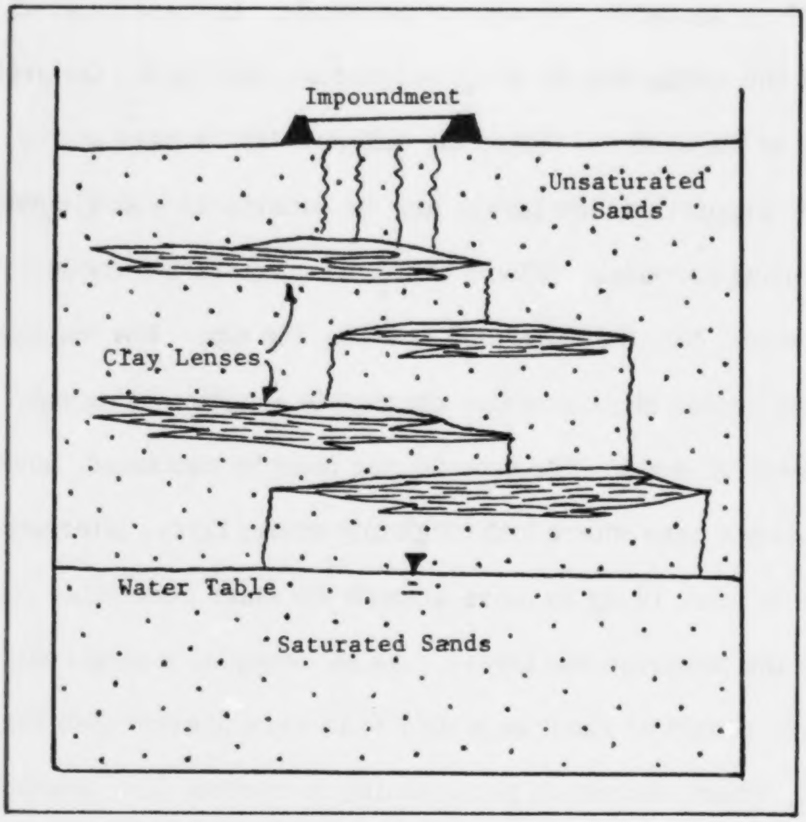

Impoundment
Unsaturated Sands
Clay Lenses
Water Table
Saturated Sands

Figure 8. Hypothetical flow paths of waste fluids seeping from a surface impoundment through unsaturated sands containing clay lenses.

Step 1, Part C. The Scoring of Step 1.

After the thickness of the unsaturated zone and the type of earth material in the unsaturated zone have been determined, refer to the Step 1 matrix (in Table 1) and record the appropriate score for the particular values of thickness and material.

Sources of information for completing Step 1.

Many data sources exist for the depth to the water table and the geologic material beneath a site. The site may have specific data available from State files if the site is permitted. The owner/operator may have data on shallow bedrock and soils available from borings or trenches made for the impoundment or nearby building foundations. Nearby water wells may provide data on the geology and ground-water levels, and adjacent road cuts can provide additional information on the subsurface.

General information is available from State agency reports such as the State geological survey, State departments of transportation soil borings, water resources agencies or universities with departments concerned with geology and ground-water resources. The United States Geological Survey also publishes reports and maintains files on ground water occurrence in each State. The U.S. Department of Agriculture, Soil Conservation Service, publishes county soils reports and maps with information on local soil profiles and bedrock, depth to the water table and depth to unweathered bedrock or parent material of the soil.

Example for determining the score for Step 1.

To score a site for Step 1, information is needed on: 1) the depth to the saturated zone and 2) the earth material of the unsaturated zone. The following example illustrates the method of scoring a site and will be utilized in all steps of the evaluation system.

A poultry processing plant, located in the Appalachian Valley and Ridge Province of a Mid-Atlantic State, operates a two acre waste treatment lagoon (about 8000 m) for disposal of poultry processing waste water. The waste treatment lagoon is shown in the site plan of Figure 9; Figure 10 gives the site location in relation to local topography.

Example Step 1, Part A. Determine the depth to the water table to establish the thickness of the unsaturated zone. In this example the depth to the water table may be obtained from the driller's log of the plant water well. Figure 11 shows the driller's report which indicates that the depth to the static water table is 33 feet (about 10 meters). This static water table level is not the seasonal high water table at this site. The seasonal high water table would be expected to occur around 25 feet (7.5 meters).

The depth to the water table could also be estimated by studying the topographic map in Figure 10 if no well data was available. The elevation of the lagoon bottom is estimated to be about 1020 feet (311 meters) Mean Sea Level as the site is located between two 1020 foot contours. The river is about 100 feet (30 meters) to the west and, in the humid eastern climate, the water table can be assumed to be the river level at the river. Since the lagoon is close to the river, the water table is estimated to be about the same elevation as the river, i. e., 990 feet (302 meters). This is determined by noting that the 980 foot (299 meters) elevation crosses the river about 1 mile (1.6 kilometers) downstream and the 1000 foot (305 meters) elevation crosses about 1 mile upstream. Interpolation between 980 and 1000 gives a river elevation of 990 feet. By estimating the lagoon elevation (1020 feet) and adjacent

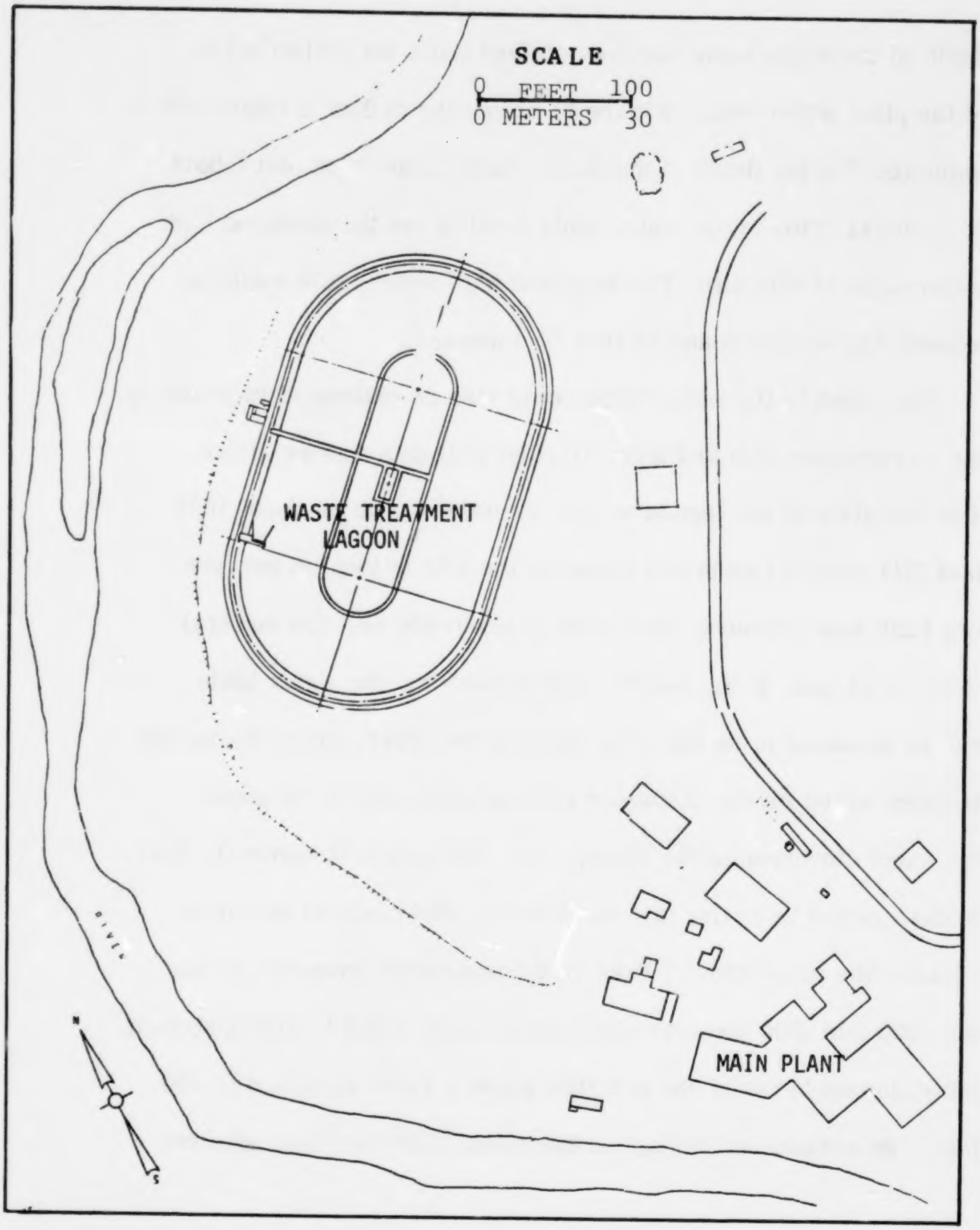

SCALE
0 FEET 100
0 METERS 30
WASTE TREATMENT LAGOON
MAIN PLANT
RIVER
N
S

Figure 9. Poultry Processing Plant site plan.

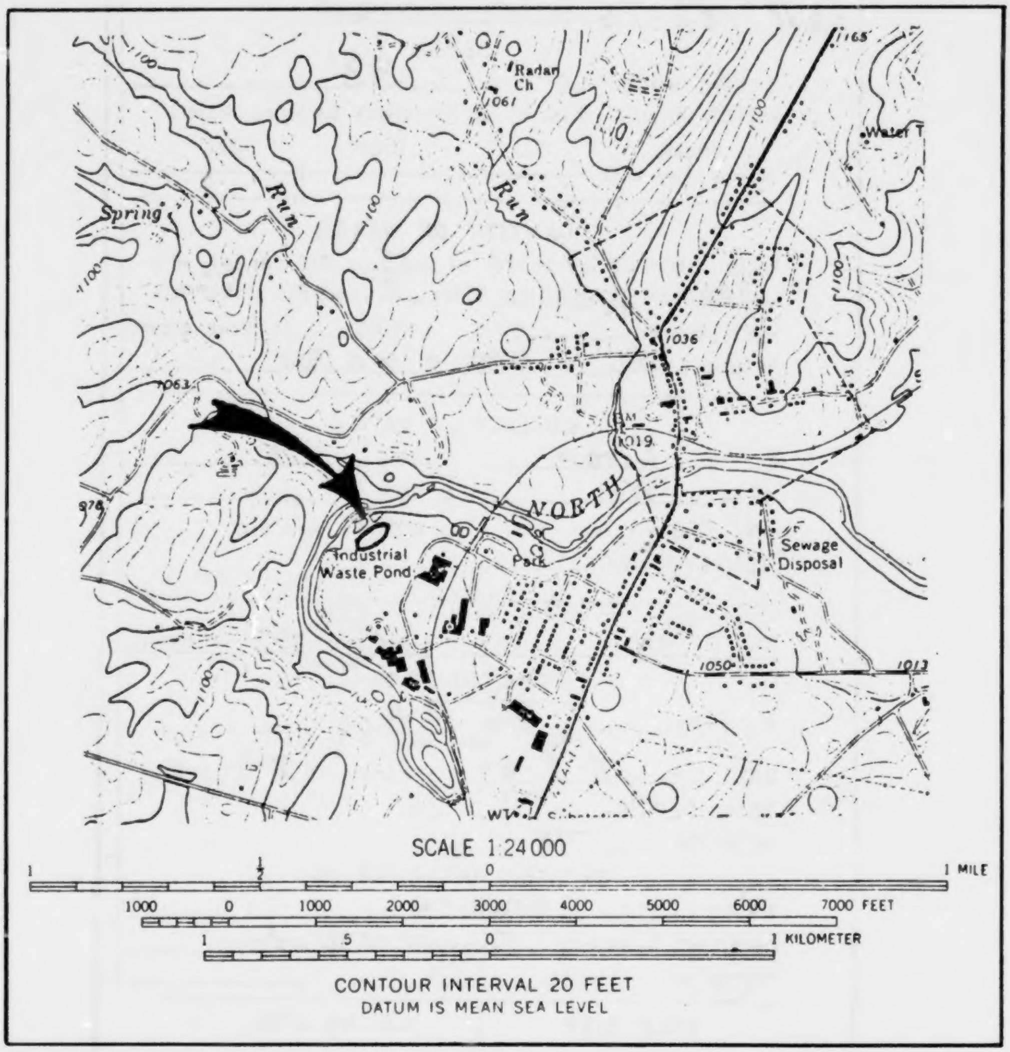
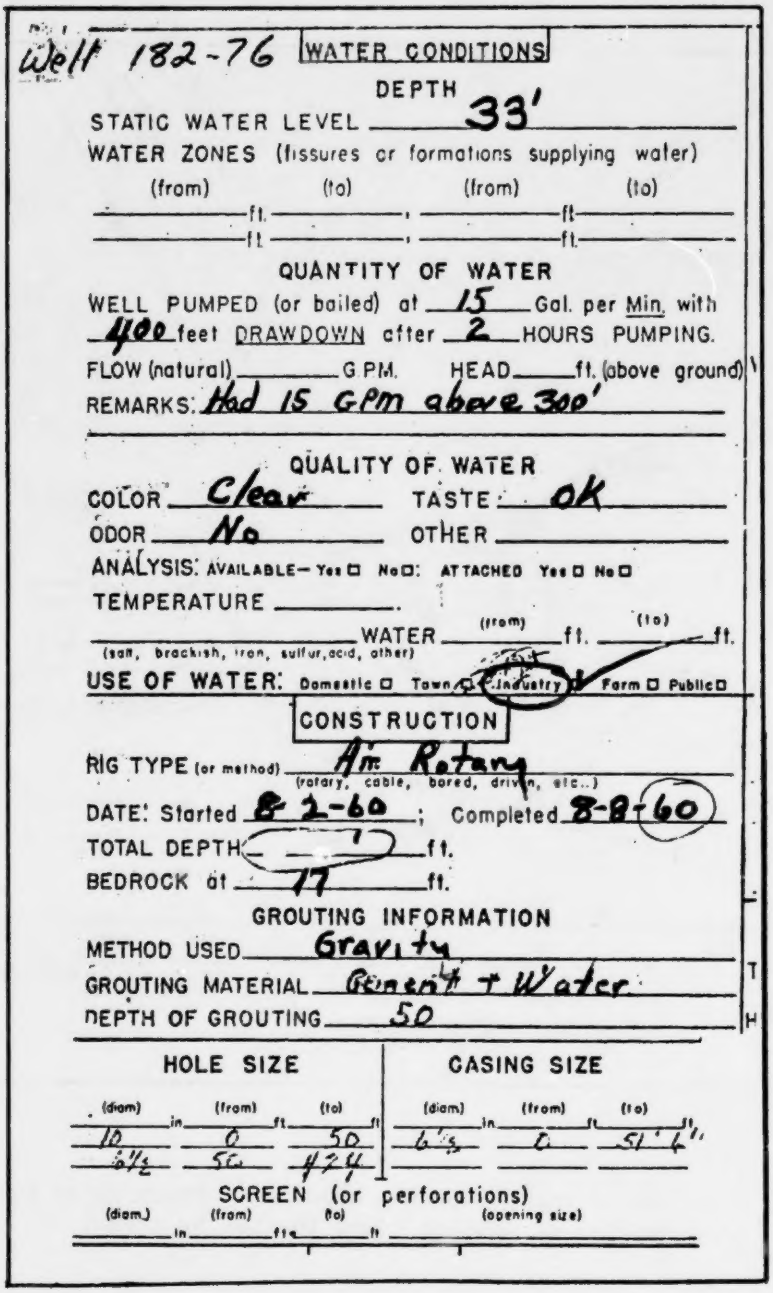

Radar
Ch
1061
1165
Water T
1100
Run
Run
Spring
1063
1036
BM
1019
NORTH
978
Industrial
Waste Pond
Park
Sewage
Disposal
1050
1013
SCALE 1:24 000
1
½
0
1 MILE
1000
0
1000
2000
3000
4000
5000
6000
7000 FEET
1
.5
0
1 KILOMETER
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

Figure 10. Portion of the 7.5 minute quadrangle topographic map of the Poultry Processing Plant (Marked by arrow).



Well 182-76 **WATER CONDITIONS**

DEPTH

STATIC WATER LEVEL 33'

WATER ZONES (fissures or formations supplying water)

(from) ____ ft. (to) ____ , (from) ____ ft. (to) ____

(from) ____ ft. (to) ____ , (from) ____ ft. (to) ____

QUANTITY OF WATER

WELL PUMPED (or bailed) at 15 Gal. per Min. with 400 feet DRAWDOWN after 2 HOURS PUMPING.

FLOW (natural) ____ G.P.M. HEAD ____ ft. (above ground)

REMARKS: Had 15 GPm above 300'

QUALITY OF WATER

COLOR Clear TASTE OK

ODOR No OTHER ____

ANALYSIS: AVAILABLE— Yes ☐ No ☐: ATTACHED Yes ☐ No ☐

TEMPERATURE ____.

____ WATER (from) ____ ft. (to) ____ ft.
(salt, brackish, iron, sulfur, acid, other)

USE OF WATER: Domestic ☐ Town ☐ [✓ Industry] ☑ Farm ☐ Public ☐

CONSTRUCTION

RIG TYPE (or method) Air Rotary
(rotary, cable, bored, driven, etc..)

DATE: Started 8-2-60 ; Completed 8-8-60

TOTAL DEPTH ____ ft.

BEDROCK at 17 ft.

GROUTING INFORMATION

METHOD USED Gravity

GROUTING MATERIAL Cement + Water

DEPTH OF GROUTING 50

HOLE SIZE

(diam) in	(from) ft	(to) ft
10	0	50
6½	50	474

CASING SIZE

(diam) in	(from) ft	(to) ft
6⅝	0	51'4"

SCREEN (or perforations)

(diam.) ____ in ____ (from) ____ ft (to) ____ ft (opening size) ____

Figure 11. Portion of the driller's report on the water supply well drilled at the Poultry Processing Plant showing the static ground-water level.

river elevations (990 feet), the water table depth is estimated at 30 feet (about 9 meters). This estimate is fairly close to the measured static water level in the well. This method of estimating ground-water levels is useful only for perennial streams and is not reliable in the arid western United States where streams are intermittent. In such cases the ground-water level is often deeper than the stream bed and may have no relationship to the stream level or topography.

Example Step 1, Part B. The second part of completing Step 1 is to estimate the composition of the earth material of the unsaturated zone. For the Poultry Processing Plant, there is a substantial amount of data available from a county geologic report, the driller's report for the water well at the site and, several test borings conducted at the lagoon site. Figure 12 and 13 show the surface bedrock configuration and the structural cross-section of the area. The bedrock at the site is the Edinburg Formation composed of shale and limestone layers tilted at about 70 degrees to the west. The Driller's report containing the well log (Figure 14) indicates that about 16 feet (about 5 meters) of unconsolidated clay and gravel overlie a considerable thickness of variable limestone down to 424 feet (129 meters).

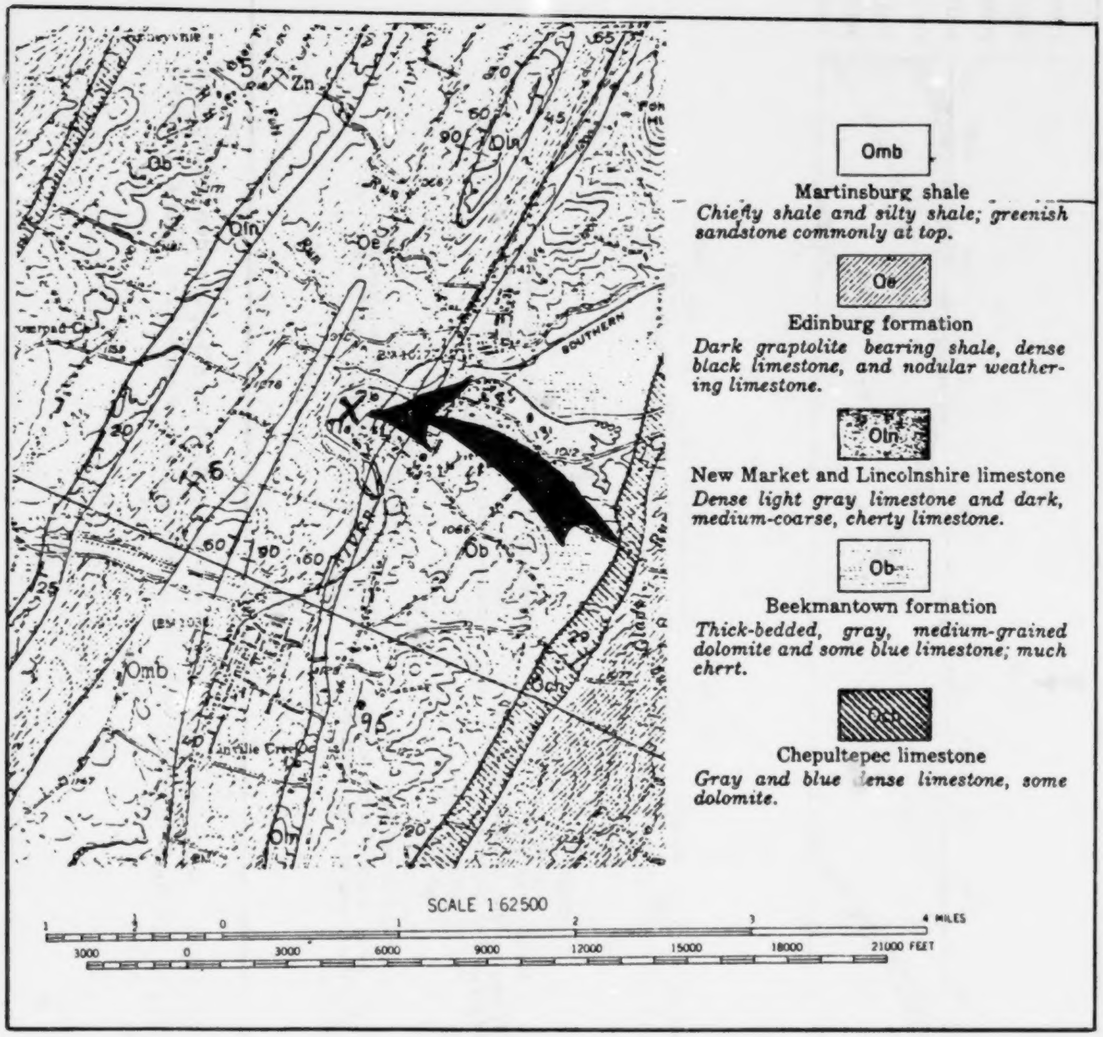
The logs of the test borings shown in Figures 15 indicate a quite variable thickness of sand and gravel (from 12 to 60 feet, or 3 to 18 meters) above limestone. It would be expected in this area of steeply tilted limestone and shale layers to have a rough, variable bedrock surface as a result of differential weathering.

Example, Step 1, Part C. After determining the thickness of the unsaturated zone (7.5 meters) and the type of earth material in the unsaturated zone, the Step 1 score can be determined from the Step 1 matrix in Table I for the following parameters:

Thickness of the unsaturated zone = 7.5 meters

Material of the unsaturated zone = 3 meters of sand and gravel
4.5 meters of limestone

As the sand, gravel and limestone are of similar hydrologic character and in the same earth material category of Step 1, their thickness can be combined so that the Step 1 score would be determined for 7.5 meters of category "I" material rated at 9C. (The presence of a liner would be noted by recording the appropriate code in the reporting form.)


X
Zn
Oe
Oln
Ob
Omb
Och
SOUTHERN
6
95
Omb
Martinsburg shale
Chiefly shale and silty shale; greenish sandstone commonly at top.
Oe
Edinburg formation
Dark graptolite bearing shale, dense black limestone, and nodular weathering limestone.
Oln
New Market and Lincolnshire limestone
Dense light gray limestone and dark, medium-coarse, cherty limestone.
Ob
Beekmantown formation
Thick-bedded, gray, medium-grained dolomite and some blue limestone; much chert.
Och
Chepultepec limestone
Gray and blue dense limestone, some dolomite.
SCALE 1:62500
1
0
1
2
3
4 MILES
3000
0
3000
6000
9000
12000
15000
18000
21000 FEET

Fugure 12. Portion of the geologic map from the County Geologic Report containing the location of the Poultry Processing Plant (marked by an X and an arrow).

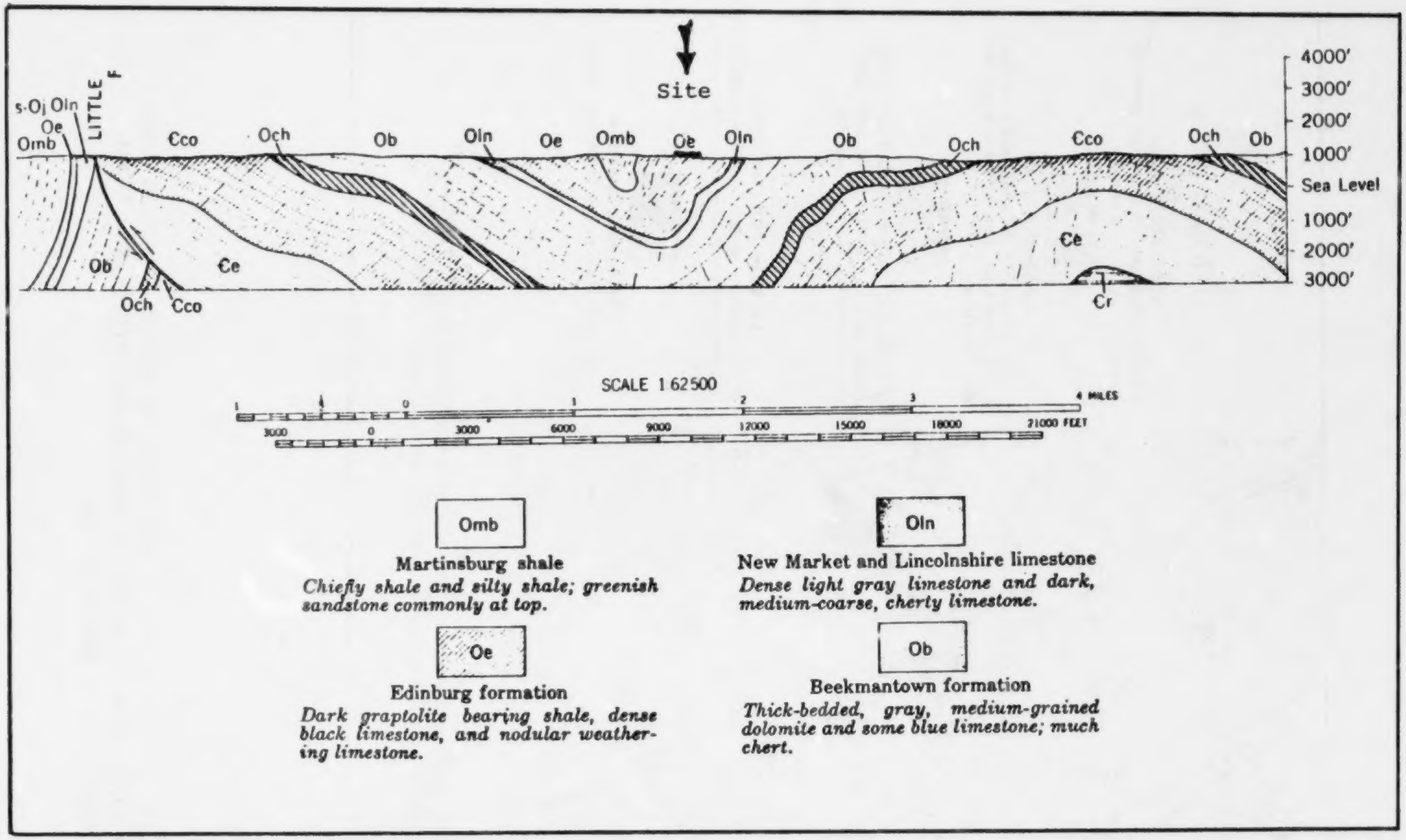
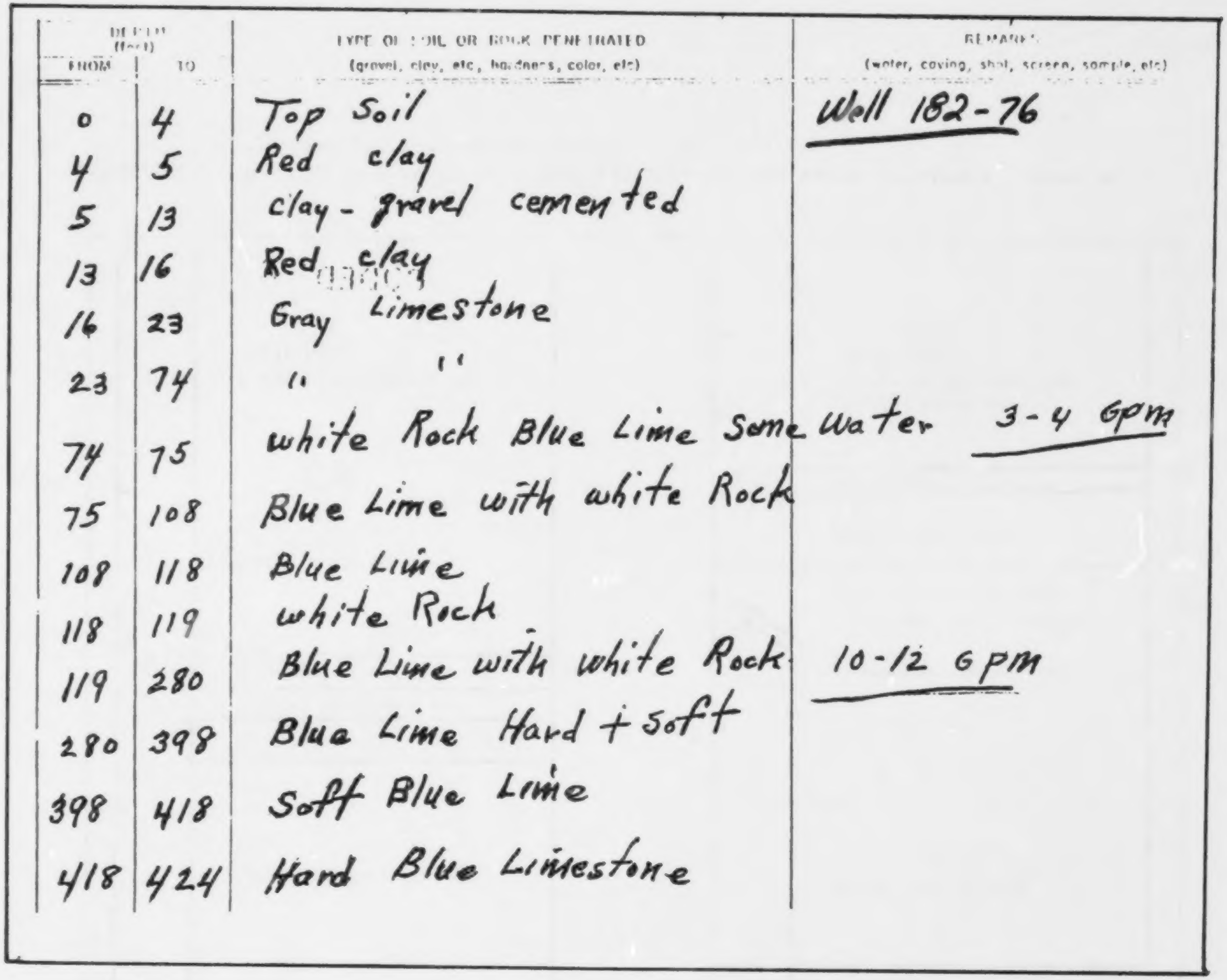

Site
s-Oj Oln
Oe
Omb
LITTLE F
Cco
Och
Ob
Oln
Oe
Omb
Oe
Oln
Ob
Och
Cco
Och
Ob
4000′
3000′
2000′
1000′
Sea Level
1000′
2000′
3000′
Ob
Ce
Och
Cco
Ce
Cr
SCALE 1 62500
4 MILES
21000 FEET
Omb
Martinsburg shale
Chiefly shale and silty shale; greenish sandstone commonly at top.
Oe
Edinburg formation
Dark graptolite bearing shale, dense black limestone, and nodular weathering limestone.
Oln
New Market and Lincolnshire limestone
Dense light gray limestone and dark, medium-coarse, cherty limestone.
Ob
Beekmantown formation
Thick-bedded, gray, medium-grained dolomite and some blue limestone; much chert.

Figure 13. Portion of a geologic cross-section from the County Geologic Report depicting the general subsurface geologic structure around the Poultry Processing Plant (marked by the arrow).



DEPTH (feet)		TYPE OF SOIL OR ROCK PENETRATED (gravel, clay, etc, hardness, color, etc)	REMARKS (water, caving, shot, screen, sample, etc)
FROM	TO		
0	4	Top Soil	Well 182-76
4	5	Red clay	
5	13	clay - gravel cemented	
13	16	Red clay	
16	23	Gray Limestone	
23	74	" "	
74	75	white Rock Blue Lime Some	Water 3-4 GPM
75	108	Blue Lime with white Rock	
108	118	Blue Lime	
118	119	white Rock	
119	280	Blue Lime with white Rock	10-12 GPM
280	398	Blue Lime Hard + soft	
398	418	Soft Blue Lime	
418	424	Hard Blue Limestone	

Figure 14. Portion of the driller's report on the water supply well drilled at the Poultry Processing Plant showing the well log.

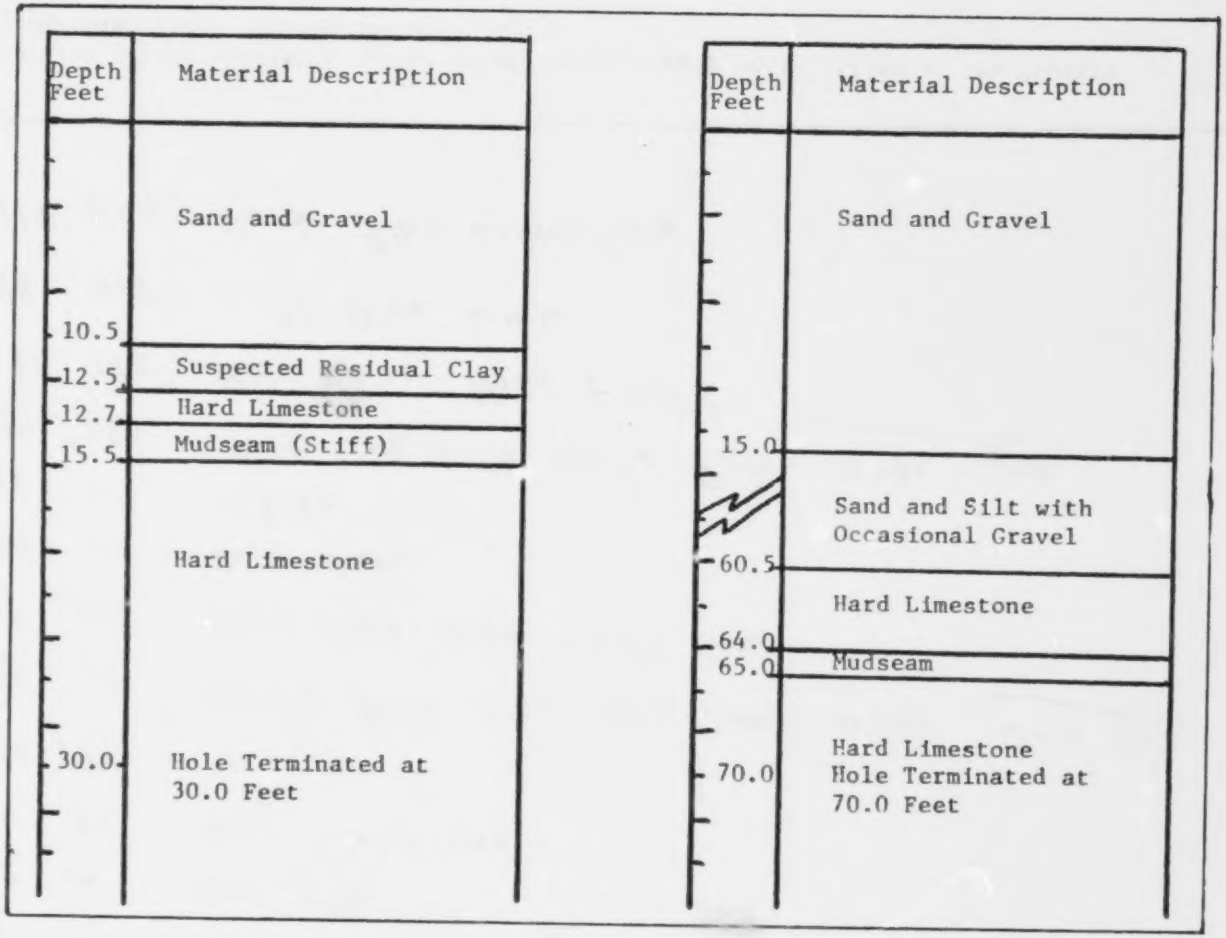

Depth Feet
Material Description
Sand and Gravel
10.5
12.5
12.7
15.5
Suspected Residual Clay
Hard Limestone
Mudseam (Stiff)
Hard Limestone
30.0
Hole Terminated at 30.0 Feet
Depth Feet
Material Description
Sand and Gravel
15.0
Sand and Silt with Occasional Gravel
60.5
Hard Limestone
64.0
65.0
Mudseam
70.0
Hard Limestone Hole Terminated at 70.0 Feet

Figure 15. Driller's logs of test borings beneath the waste treatment lagoon at the Poultry Processing Plant.

STEP 2

GUIDANCE FOR RATING GROUND WATER AVAILABILITY

Determining the ground-water availability ranking.

The ability of the aquifer to transmit ground water depends upon the permeability and saturated thickness of the aquifer. Step 2 provides the guidance to determine the ground-water availability rating of the aquifer. Since this evaluation system is a first-round approximation, the ground-water availability rating is not exact, but an approximation. The categories of earth material which make up the saturated zone are the same categories as used in Step 1 but have been combined into good, fair and poor aquifer material categories (Table II).

Estimate the aquifer's saturated thickness (in meters) and the type of earth material in the saturated zone as done for Step 1. Choose the appropriate ranking in the matrix of Step 2 (Table II) from the respective saturated thickness and earth material category. The letter accompanying the ranking is for the purpose of identifying what the ranking's derivation is if, at sometime in the future, there is reason to verify the number.

Sources of information for completing Step 2 .

Sources of information in determining the parameters of Step 2 are similar to those of Step 1.

TABLE II

Step 2. Rating of the Ground Water Availability

	Earth Material Category	I	II	III
GUIDELINES FOR DETERMINING CATEGORY	Unconsolidated Rock	Gravel or sand	Sand with ≤ 50% clay	Clay with < 50% sand
	Consolidated Rock	Cavernous or Fractured Rock, Poorly Cemented Sandstone, Fault Zones	Moderately to Well Cemented Sandstone, Fractured Shale	Siltstone, Unfractured Shale and other Impervious Rock
	Representative Permeability in gpd/ft^2 in cm/sec	 > 2 $> 10^{-4}$	 $0.02 - 2$ $10^{-6} - 10^{-4}$	 < 0.02 $< 10^{-6}$
	RATING MATRIX			
	Thickness of Saturated Zone (Meters) ≥ 30	6A	4C	2E
	3-30	5A	3C	1E
	≤ 3	3A	1C	0E

Example, Step 2.

The type of earth material of the saturated zone can be determined from the county geologic map and cross-section (Figures 11 and 12) and the driller's log of Figure 13. Generally, the material down to greater than 400 feet (122 meters) below the surface is limestone with shale interbeds. From the drillers' report of the pump test (shown in Figure 10) the water supply well near the surface impoundment had 400 feet of drawdown at 15 gpm (57 liters per minute) after 2 hours pumping. From this data the limestone is very tight with little permeability and very little development of open fractures. The category in Step 2 for rating this material would be category II as the saturated zone is capable of producing water but only at moderate to low quantites. From the above sources of information the thickness of the saturated zone is estimated to be several hundred feet. The score for the ground-water availability ranking would be determined for earth material category II and greater than 30 meters thickness, i. e., the Step 2 ranking is "4C."

STEP 3

GUIDANCE FOR RATING THE GROUND-WATER QUALITY

Ground-water quality is a determinant of the ultimate usefulness of the ground water. Waste disposal sites situated in an area of poor quality ground water unsuitable as a drinking water supply would not present the same degree of pollution potential to ground water as the same site situated in an area having very good quality ground water. Step 3 (Table III) is used to determine the ranking of the aquifer's ground-water quality. The ranking is based upon the criteria that has been set forth in the proposed Underground Injection Control Regulations (40 CFR Part 146) of the Safe Drinking Water Act of 1974 (P. L. 93-523). The descriptions are to be used as basic guidelines to assist the investigator in arriving at the appropriate rating of ground-water quality. Consideration of only the background water quality of the aquifer is intended.

Determine the Aquifer Quality Ranking

Determine the total dissolved solids content of the ground water and apply it to the appropriate rating in Step 3, Table III. If the ground water is presently a drinking water supply, the ranking would be a "5" regardless of its total dissolved solids content.

Table III

Step 3. Rating the Ground-Water Quality

Rating	Quality
5	≤ 500 mg/l TDS or a current drinking water source
4	> 500 - ≤ 1000 mg/l TDS
3	> 1000 - ≤ 3000 mg/l TDS
2	> 3000 - ≤ 10,000 mg/l TDS
1	> 10,000 mg/l TDS
0	No ground water present

Sources of information for completing Step 3 .

Ground-water quality data for the determination of the Step 3 rating may be obtained from several sources. If the aquifer is presently used by individuals or communities, no further documentation is required. If industries or agriculture use the ground water, but not currently for human consumption, further quality data may be required for the rating. Many State agencies (i. e., geological surveys, health departments, water boards or commissions and State engineers) and the U. S. Geological Survey have considerable water quality data on file, in published reports and as maps outlining the ground-water quality in the States by aquifer.

Example, Step 3.

The quality of the ground water beneath the Poultry Processing Plant site would be rated "5" since the aquifer does supply drinking water, and in addition based upon driller's report, general State files and published reports, the aquifer has an overall good quality with very low total dissolved solids.

STEP 4

GUIDANCE FOR RATING THE WASTE HAZARD POTENTIAL

Contaminants that may enter ground water have been evaluated by their potential for causing harm to human health (Hazard Potential). The hazard potential rankings for contaminants range from 1 to 9 with 1 being least hazardous and 9 being most hazardous.

Contaminants and their hazard potential rankings are classified in two ways: (1) by contaminant source (Table IV), and (2) by contaminant type (Table V). Standard Industrial Classification (SIC) numbers are used to classify sources. Common sources and types of contaminants and their hazard potential ranges are illustrated in Figure 16.

There are many variables that influence a substance as it enters the ground-water environment such that its true hazard potential as a ground-water contaminant is not likely to be the same as its apparent hazard potential. Most such variables tend to reduce hazard potentials. The hazard potential rankings considered the following factors and their interactions.

TOXICITY - The ability of a substance to produce harm in or on the body of living organisms is extremely important in ranking the hazard potential of that substance. While some substances are highly toxic they may possess low mobility and thus be assigned a lower hazard potential ranking than a less toxic but highly mobile substance.

TABLE IV

CONTAMINANT HAZARD POTENTIAL RANKINGS OF WASTE, CLASSIFIED BY SOURCE FOR STEP 4.

SIC Number		Description of Waste Source	Hazard Potential Initial Rating
01		AGRICULTURAL PRODUCTION - CROPS	1-2
02		AGRICULTURAL PRODUCTION - LIVESTOCK	
	021	Livestock, except Dairy, Poultry and Animal Specialties	3 (5 for Feedlots)
	024	Dairy Farms	4
	025	Poultry and Eggs	4
	027	Animal Specialties	2-4
	029	General Farms, Primarily Livestock	2
10		METAL MINING	
	101	Iron Ores	4
	102	Copper Ores	6
	103	Lead and Zinc Ores	5
	104	Gold and Silver Ores	6
	105	Bauxite and other Aluminum Ores	5
	106	Ferroalloy Ores Except Vanadium	5
	108	Metal Mining Services	4
	1092	Mercury Ore	6
	1094	Uranium-Radium-Vanadium Ores	7
	1099	Metal Ores not elsewhere classified	5
11		ANTHRACITE MINING	7
12		BITUMINOUS COAL AND LIGNITE MINING	7
13		OIL AND GAS EXTRACTION	
	131	Crude Petroleum and Natural Gas	7
	132	Natural Gas Liquids	7
	1381	Drilling Oil and Gas Wells	6
	1382	Oil and Gas Field Exploration Services	1
	1389	Oil and Gas Field Services not elsewhere classified	Variable depending Activity
14		MINING AND QUARRYING OF NON-METALLIC MINERALS, EXCEPT FUELS	
	141	Dimension Store	2
	142	Crushed and Broken Stone, Including Riprap	2
	144	Sand and Gravel	2
	145	Clay, Ceramic, and Refractory Minerals	2-5
	147	Chemical and Fertilizer Mineral Mining	4-7
	148	Nonmetallic Minerals Services	1-7
	149	Miscellaneous Non-metallic Minerals, except Fuels	2-5

(TABLE IV continued)

SIC Number	Description of Waste Source	Hazard Potential Initial Rating
16	CONSTRUCTION OTHER THAN BUILDING CONSTRUCTION	
1629	Heavy Construction, not elsewhere classified (Dredging, especially in salt water)	4
20	FOOD AND KINDRED PRODUCTS	
201	Meat Products	3
202	Dairy Products	2
203	Canned and Preserved Fruits and Vegetables	4
204	Grain Mill Products	2
205	Bakery Products	2
206	Sugar and Confectionery Products	2
207	Fats and Oils	3
208	Beverages	2-5
209	Misc. Food Preparation and Kindred Products	2
22	TEXTILE MILL PRODUCTS, ALL EXCEPT LISTINGS BELOW	
223	Broad Woven Fabric Mills, Wool (including dyeing and finishing)	6
226	Dying and Finishing Textiles, except Wool Fabrics and Knit Goods	6
2295	Coated Fabrics, Not Rubberized	6
24	LUMBER AND WOOD PRODUCTS, EXCEPT FURNITURE	
241	Logging Camps and Logging Contractors	2
242	Sawmills and Planing Mills	2
2435	Hardwood Veneer and Plywood	4
2436	Softwood Veneer and Plywood	4
2439	Structural Wood Members, not elsewhere classified (laminated wood-glue)	3
2491	Wood Preserving	5
2492	Particle Board	4
2499	Wood Products, not elsewhere classified	2-5
26	PAPER AND ALLIED PRODUCTS	
261	Pulp Mills	6
262	Paper Mills Except Building Paper Mills	6
263	Paperboard Mills	6

(TABLE IV continued)

SIC Number		Description of Waste Source	Hazard Potential Initial Rating
28		CHEMICALS AND ALLIED PRODUCTS[1]	
	2812	Alkalies and Chlorine	7-9
	2813	Industrial Gases	
	2816	Inorganic Pigments	3-8
	2819	Industrial Inorganic Chemicals, not elsewhere classified	3-9
	2821	Plastic Materials, Synthetic Resins, and Nonvulcanizable Elastomers	6-8
	2822	Synthetic Rubber (Vulcanizable Elastomers)	6-8
	2823	Cellulose Man-Made Fibers	6-8
	2824	Synthetic Organic Fibers, except Cellulosic	6-8
	2831	Biological Products	6-9
	2833	Medicinal Chemicals and Botanical Products	3-8
	2834	Pharmaceutical Preparations	6-9
	2841	Soap and Other Detergents, except specialty cleaners	4-6
	2842	Specialty Cleaning, Polishing and Sanitation Preparation	3-8
	2843	Surface Active Agents, Finishing Agents, Sulfonated Oils and Assistants	6-8
	2844	Perfumes, Cosmetics, and other Toilet Preparations	3-6
	2851	Paints, Varnisher, Lacquers, Enamels, and Allied Products	5-8
	2861	Gum and Wood Chemicals	5-8
	2865	Cyclic (coal tar) Crudes, and Cyclic Intermediates, Dyes and Organic Pigments (Lakes and Toners)	6-9
	2869	Industrial Organic Chemicals, not elsewhere listed	3-9

(TABLE IV continued)

SIC Number		Description of Waste Source	Hazard Potential Initial Rating
	2873	Nitrogenous Fertilizers	7-8
	2874	Phosphatic Fertilizers	7-8
	2875	Fertilizer Mixing Only	5
	2879	Pesticides and Agricultural Chemicals, Not Elsewhere Listed	5-9
	2891	Adhesives and Sealants	5-8
	2892	Explosives	6-9
	2893	Printing Ink	2-5
	2895	Carbon Black	1-3
	2899	Chemicals and Chemical Preparations, not Elsewhere Listed	3-9
29		PETROLEUM REFINING AND RELATED INDUSTRIES	
	291	Petroleum Refining	8
	295	Paving and Roofing Materials	7
	299	Misc. Products of Petroleum and Coal	7
30		RUBBER AND MISCELLANEOUS PLASTICS PRODUCTS	
	301	Tires and Inner Tubes	6
	302	Rubber and Plastic Footwear	6
	303	Reclaimed Rubber	6
	304	Rubber and Plastics Hose and Belting	4
	306	Fabricated Rubber Products, not Elsewhere Classified	4
31		LEATHER AND LEATHER PRODUCTS	
	311	Leather Tanning and Finishing	8
		(Remaining Three-Digit Codes)	1-3
32		STONE, CLAY, GLASS, AND CONCRETE PRODUCTS	
	321	Flat Glass	4
	322	Glass and Glassware, Pressed or Blown	4
	324	Cement, Hydraulic	3
	3274	Lime	3
	3291	Abrasive Products	3
	3292	Asbestos	3
	3293	Gaskets, Packing, and Sealing Devices	3
33		PRIMARY METAL INDUSTRIES (EXCEPT AS NOTED BELOW)	3
	3312	Blast Furnaces, Steel Works, and Rolling and Finishing Mills	6
	333	Primary Smelting and Refining of Nonferrous Metals	7

(TABLE IV continued)

SIC Number		Description of Waste Source	Hazard Potential Initial Rating
34		FABRICATED METAL PRODUCTS, EXCEPT MACHINERY AND TRANSPORTATION EQUIPMENT (EXCEPT AS NOTED BELOW)	5
	347	Coating, Engraving, and Allied Services	8
	3482	Small Arms Ammunition	7
	3483	Ammunition, Except for Small Arms not Elsewhere Classified	7
	3489	Ordnance and Accessories, not Elsewhere Classified	7
	349	Misc. Fabricated Metal Products	3-6
35		MACHINERY, EXCEPT ELECTRICAL	5-7
36		ELECTRICAL AND ELECTRONIC MACHINERY, EQUIPMENT AND SUPPLIES (EXCEPT AS NOTED BELOW)	5-7
	3691	Storage Batteries	8
	3692	Primary Batteries, Dry and Wet	8
37		TRANSPORTATION EQUIPMENT	5-8
38		MEASURING, ANALYZING, AND CONTROLLING INSTRUMENTS; PHOTOGRAPHIC, MEDICAL, AND OPTICAL GOODS; WATCHES AND CLOCKS (EXCEPT AS NOTED BELOW)	4-6
	386	Photographic Equipment and Supplies	7
39		MISCELLANEOUS MANUFACTURING INDUSTRIES	3-7
49		ELECTRIC, GAS, AND SANITARY SERVICES	
	491	Electric Services	3-5
	492	Gas Production and Distribution	3
	494	Water Supply	2
	4952	Sewerage Systems	2-5
	4953	Refuse Systems (except Municipal Landfills)	2-9
	496	Steam Supply	2-4

TABLE V

CONTAMINANT HAZARD POTENTIAL RANKINGS OF WASTES, CLASSIFIED BY TYPE[1] FOR STEP 4

	Description	Hazard Potential Initial Rating	ID Number *
A.	SOLIDS		
	Ferrous Metals	1-4[2]	1100
	Non-Ferrous Metals	1-7[2]	1200
	Resins, Plastics and Rubbers	2	1300
	Wood and Paper Materials (except as noted below)	2	1400
	- Bark	4	1401
	Textiles and Related Fibers	2	1500
	Inert Materials (except as noted below)	2	1600
	- Sulfide Mineral-Bearing Mine Tailings	6	1601
	- Slag and other Combustion Residues	5	1602
	- Rubble, Construction & Demolition Mixed Waste	3	1603
	Animal Processing Wastes (Except as noted below)	2-4	1700
	- Processed Skins, Hides and Leathers	6	1701
	- Dairy Wastes	4	1702
	- Live Animal Wastes-Raw Manures (Feedlots)	5	1703
	- Composts of Animal Waste	2-4	1704
	- Dead Animals	5	1705
	Edible Fruit and Vegetable Remains - Putrescables	2-3	1800
B.	LIQUIDS		
	Organic Chemicals (Must be chemically Classified)[2]		2000
	- Aliphatic (Fatty) Acids	3-5	2001
	- Aromatic (Benzene) Acids	7-8	2002
	- Resin Acids		2003
	- Alcohols	5-7	2004
	- Aliphatic Hydrocarbons (Petroleum Derivatives	4-6	2005
	- Aromatic Hydrocarbons (Benzene Derivatives)	6-8	2006
	- Sulfonated Hydrocarbons	7-8	2007
	- Halogenated Hydrocarbons	7-9	2008
	- Alkaloids	7-9	2009
	- Aliphatic Amines and Their Salts	1-4	2010
	- Anilines	6-8	2011
	- Pyridines	2-6	2012
	- Phenols	7-9	2013
	- Aldehydes	6-8	2014
	- Ketones	6-8	2015
	- Organic Sulfur Compounds (Sulfides, Mercaptans)	7-9	2016
	- Organometallic Compounds	7-9	2017
	- Cyanides	7-9	2018
	- Thiocyanides	2-6	2019
	- Sterols		2020
	- Sugars and Cellulose	1-4	2021
	- Esters	6-8	2022

Description	Hazard Potential Initial Rating	ID Number*
Inorganic Chemicals (Must be Chemically Classified)[2]		2100
- Mineral and Metal Acids	5-8	2101
- Mineral and Metal Bases	5-8	2102
- Metal Salts, Including Heavy Metals	6-9	2103
- Oxides	5-8	2104
- Sulfides	5-8	2105
- Carbon or Graphite	1-3	2106
Other Chemical Process Wastes Not Previously Listed (Must be Chemically Classified)[2]		2200
- Inks	2-5	2201
- Dyes	3-8	2202
- Paints	5-8	2203
- Adhesives	5-8	2204
- Pharmaceutical Wastes	6-9	2205
- Petrochemical Wastes	7-9	2206
- Metal Treatment Wastes	7-9	2207
- Solvents	6-9	2208
- Agricultural Chemicals (Pesticides, Herbicides, Fungicides, etc.)	7-9	2209
- Waxes and Tars	4-7	2210
- Fermentation and Culture Wastes	2-5	2211
- Oils, including Gasoline, Fuel Oil, etc.	5-8	2212
- Soaps and Detergents	4-6	2213
- Other Organic or Inorganic Chemicals, includes Radioactive Wastes	2-9	2214
Conventional Treatment Process Municipal Sludges	4-8	2300
- From Biological Sewage Treatment	4-8	2301
- From Water Treatment and Conditioning Plants (Must be Chemically Classified)[2]	2-5	2302

* ID Number is for identification of waste type in the Reporting Form.

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[1] Classification based on material in Environmental Protection Agency Publication, 670-2-75-024, pages 79-85, Prepared by Arthur D. Little, Inc. and published in 1975.

[2] For individual material ranking refer to solubility-toxicity tables prepared by Versar, Inc. for the Environmental Protection Agency.

MOBILITY - The material must be able to enter the ground-water environment and travel with the ground water. Certain substances are essentially immobile (eg., asbestos fibers) while others are highly mobile with most substances falling between these extremes.

PERSISTENCE - Some substances such as halogenated hydrocarbons decay or degrade very slowly and receive a higher hazard potential ranking than other equally toxic materials that decay more rapidly.

VOLUME - Some substances, such as tailings or slimes from mining operations, are only moderately toxic but because they are produced in enormous quantities are given a somewhat higher hazard potential ranking.

CONCENTRATION - Substances entering the ground-water environment in concentrations which could potentially endanger human health are ranked. Concentration may decrease with dilution and attenuation but the amount of decrease at a given place depends, in part, on waste mobility, waste interaction with soils and aquifer material, etc.

Determining the Waste Hazard Potential for Step 4 .

Wastes may be simple in composition, but most are complex and the hazard potential rankings given in Tables IV and V are maximum values based on the most hazardous substance present in the contaminant. Such rankings are, of necessity, generalizations because of the unknown interactions that occur between substances and the variables of the ground-water environment.

For those substances or sources that show a hazard potential ranking range (e. g., 5-8) additional information concerning the specific nature of the source or contaminant is required for assigning a specific ranking. Specific rankings in such cases must be personal judgements by the assessor. Additional information for determining a specific ranking may be available from the source of the contaminant, i. e., the industry may be able to supply specific information about the contaminant. In the event specific information is not available from the source, additional information may be obtained from an examination of descriptions of average contaminant characteristics listed in several publications cited below. For cases when there is considerable pretreatment of the waste, the ranking may be lowered to the bottom of its range. If no additional information is available, the first round approximation ranking must assume the worst case and a low confidence rating be given the ranking.

If sufficient information exists about the material (i. e., exact composition, concentration, volume, treatment prior to coming in contact with the ground, etc.) the rating may be lowered. In considering whether to lower the rating, some compounds degrade aerobically or anaerobically and the products of degradation are more hazardous than the parent chemical. Initial rankings may be modified downward provided:

1. The hazardous material in question has been effectively treated to lower its hazard potential as a ground-water pollutant. Several references describe best available methods for treating contaminants to reduce their toxicity, for example see:

- Sax, 1965, Dangerous Properties of Industrial Materials.
- Identification of Potential contaminants of underground water sources from land spills, by Versar, Inc. (Task II of EPA contract No. 68-01-4620.
- EPA, 1973, Report to Congress on Hazardous Waste Disposal
- Powers, 1976, How to Dispose of Toxic Substances and Industrial Wastes.

2. It can be shown that the hazardous material in question has low mobility in the specific site it is contaminating. Most solid and inert substances have low mobility. Substances with high solubilities tend to be most mobile. Mobility depends on a complex interplay of many factors and only a few substances have been studied sufficiently to predict with any degree of confidence their specific mobilities at a specific site.

3. The volume and/or concentration of the hazardous material is so small that there is a good probability that it will be diluted to safe (drinking water standard) levels at the point of concern.

Example for Determining the Score for Step 4 .

The waste in the Poultry Processing Plant lagoon is a meat product waste, SIC number 201 and would receive a "3" rating.

STEP 5

DETERMINATION OF THE SITE'S OVERALL GROUND-WATER CONTAMINATION POTENTIAL

After the site has been rated on Steps 1, 2, 3 and 4, the overall ground-water contamination potential of the site can be determined by totalling these scores. This overall score allows a comparison of one site with other rated sites by indicating the general, overall contamination potential. Sites may be rated identically, yet be very different in one or several of the parameters included in the overall score; thus the overall score of Step 5 should be used with caution in assessing a particular site's potential to allow ground-water contamination. In addition, this overall score cannot be used to assess the actual amount of ground-water contamination at the site. The score is only for relative comparison with other sites. An actual determination of ground-water contamination requires an intensive on-site investigation.

EPA has not formulated an interpretation of the overall ground water contamination score other than as a relative means to prioritize sites.

Step 5. Determination of the Site's Ground-Water Contamination Potential Rating.

The site's ground-water contamination potential rating is the addition of the rating scores for the first four steps:

Contamination Potential = Step 1 + Step 2 + Step 3 + Step 4.

The highest ground-water contamination potential rating a site can receive is "29" while the lowest is "1."

Example for determining the score for Step 5.

The overall ground-water contamination potential score for the Poultry Processing Plant lagoon is determined in Step 5 by adding the scores from Steps 1, 2, 3, and 4:

Step 5 Rating = Step 1 + Step 2 + Step 3 + Step 4

= 9 + 4 + 5 + 3 = 21

STEP 6

DETERMINATION OF THE POTENTIAL ENDANGERMENT TO CURRENT WATER SUPPLIES

The distance from the impoundment to a ground or surface water source of drinking water and the determination of anticipated flow direction of the waste plume are used to ascertain the potential endangerment to current water supplies presented by the surface impoundment. For many assessments this step can be accomplished by measuring the horizontal distance on a 7.5 topographic map, or similar scale. In order to use this step, the anticipated direction of ground water flow within 1600 meters (1 mile) of the impoundment must be determined. Ground-water movement depends upon natural ground-water flow direction, variations due to pumping wells, mounding of the ground water beneath the site and other factors influencing flow direction, such as faults, fractures and other geologic features.

In the case of artesian wells, the anticipated flow direction of the waste plume generally would not be in the direction of the artesian well intake. Artesian wells are located in confined aquifers separated hydraulically from the surface sources of contamination by relatively impermeable confining layers, and wells tapping the confined zone generally will not be drawing ground water from upper zones.

Artesian wells should not be considered in this step unless there is an indication that the anticipated flow direction of the contaminated ground water would be in the direction of that well. To score Step 5, prioritized cases (cases A-D) have been established for rating the site according to the potential magnitude of endangerment to current sources. These priorities are detailed in Step 6 (Table VI). To score a site when a water table is nearly flat and the flow direction is indeterminable, a circle with a 1600 meter radius should be drawn around the site for designating the area of concern. In this situation the evaluator would use the same criteria, in sequential order, begining with Case A, Case B, and then Case D, eliminating Case C.

After the distance has been determined, use the Step 6 rating matrix to determine the rating under the column of the appropriate case.

TABLE VI

Step 6. Rating the Potential Endangerment to a Water Supply

Case A	-	Highest Priority: Rate the closest water well within 1600 meters of the site that is in the anticipated direction of waste plume movement.
Case B	-	Second Priority: If there is no well satisfying Case A, rate the closest surface water within 1600 meters of the site that is in the anticipated direction of the waste plume movement.
Case C	-	Third Priority: If no surface water or water well satisfying Case A or B exists, rate the closest water supply well or surface water supply within 1600 meters of the site that is not in the anticipated direction of waste plume movement.
Case D	-	Lowest Priority: If there are no surface waters or water wells within 1600 meters of the site in any direction, rate the site as "0D."

Select the appropriate rating for the given distance and case:

Distance (Meters)	Case A	Case B	Case C	Case D
≤ 200	9A	8B	7C	-
>200, ≤ 400	7A	6B	5C	-
>400, ≤800	5A	4B	3C	-
>800, ≤1600	3A	2B	1C	-
>1600				0D

Example for determining the score for Step 6.

The potential health hazard to existing water supply sources which the Poultry Processing Plant presents is found by determining what types of water supplies are present and their distances from the lagoon. The drilled well described in Figure 11 is for industrial water supply. Surface water (a river) is within about 30 meters of the lagoon as shown in Figure 9. Step 6 requires an estimation of the anticipated flow direction. In this example, the anticipated flow of the waste plume is to the river. The rating of Step 6 would be based on Case B, and would be scored "8B".

STEP 7

DETERMINING THE INVESTIGATOR'S DEGREE OF CONFIDENCE

The evaluation of a surface impoundment's ground-water contamination potential involves three steps and about twice as many separate variables. In many situations the investigator will not have comprehensive information concerning the variables and will have to evaluate the site on the basis of estimation or approximation. For this reason a rating of the investigator's confidence in scoring each step will be made. The following outline is intended to assist the investigator in rating the confidence of the data for each step, with "A" the highest confidence, "C" the lowest.

Step 1 confidence rating for determining the earth material of the unsaturated zone.

Rating	Basis for Determination of Rating
A	Driller's logs containing reliable geologic descriptions and water level data; U. S. Department of Agriculture soil survey used in conjunction with large scale, modern geologic maps. Published ground-water reports on the site.
B	Soil surveys or geologic maps used alone.

	General ground-water reports. Drillers' logs with generalized descriptions. Drillers logs or exposures such as deep road cuts near the site of contamination allowing interpolation within the same general geologic unit.
C	On site examination with no subsurface data and no exposures of subsurface conditions nearby. Estimation of water levels or geology based on topography and climate. Extrapolations of well logs, road cuts, etc. where local geology is not well known. Estimation based on generalized geologic maps. Estimations based on topographic analysis.

Step 2 confidence rating for determining the ground-water availability ranking.

This step involves the earth material categorization and thickness of the aquifer's saturated zone. The confidence rating for Step 2, Part A follows the same basis as Step 1, Part B above.

Step 3 confidence rating for determining background ground-water quality.

Rating	Basis for Determination of Rating
A	Water quality analyses indicative of background ground-water quality from wells at the site or nearby wells or springs or known drinking water supply wells in vicinity.

B	Local, county, regional and other general hydrogeology reports published by State or Federal agencies on background water quality. Interpolation of background ground-water quality from base flow water quality analyses of nearby surface streams.
C	Estimates of background ground-water quality from mineral composition of aquifer earth material.

Step 4 confidence rating for waste character.

Rating	Basis for Determination of Rating
A	Waste character rating based on specific waste type.
B	Waste character rating based on SIC category.

Step 6 confidence rating for determination of the anticipated direction of waste plume movement.

Rating	Basis for Determination of Rating
A	Accurate measurements of elevations of static water levels in wells, springs, swamps, and permanent streams in the area immediately surrounding the site in question. Ground-water table maps from published State and Federal reports.

B	Estimate of flow direction from topographic maps in non cavernous area having permanent streams and humid climate.
	Estimate of flow direction from topographic maps in arid regions of low relief containing some permanent streams.
C	Estimate of flow direction from topographic maps in cavernous, predominantly limestone areas (karst terrain).
	Estimate of flow direction from topographic maps in arid regions of highly irregular topography having no permanent surface streams.

Example for determining the confidence rating for each step.

Based upon the guidance just presented, the confidence ratings for the Poultry Processing Plant are:

	Confidence Rating
Step 1	A--Based upon measurement in on site well.
Step 2	A--Based upon well logs of on site well.
Step 3	A--Based upon water well analyses.

Step 4	B--Based upon SIC category.
Step 6	B--Estimate of flow direction from topographic map in humid region.

STEP 8

MISCELLANEOUS IDENTIFIERS

This step allows the evaluator to identify any additional significant variable not noted in the rating system. Such parameters are:

Identifier

R - The site is located in a ground-water recharge area,

D - The site is located in a ground-water discharge area,

F - The site is located in a flood plain and is susceptable to flood hazard,

E - The site is located in an earthquake prone area,

W - The site is located in the area of influence of a pumping water supply well,

K - The site is located in karst topography or fractured, cavernous limestone region.

C - The ground water under the site has been contaminated by man-made causes (i. e., road salt, feed lot, industrial waste).

M - Known ground-water mound exists beneath the site.

I - Interceptor wells or other method employed to inhibit contaminated ground-water migration (endangerment to water supply wells may be reduced).

STEP 9

RECORD THE FINAL SCORE

In order to present the rating scores from the previous nine steps of the evalution system in a logical manner, Step 9 provides a systematic format in which the evaluation of the site can be recorded. The nine steps are not recorded in numerical order as the focus of the evaluation is on the ground-water pollution potential score of Step 5. Thus, Step 5 is listed first, followed by Steps 1, 2, 3, 4, 6 and 8. The example of the Poultry Processing Plant waste treatment lagoon has been listed on page 63 on the following sample reporting form. The confidence scores of Step 7 have been distributed among the appropriate steps.

TABLE VII

RATING OF THE GROUND WATER POLLUTION POTENTIAL:

9	C	A	4	C	A	5	A	3	B	2	1	8	B	B	R	F	
Unsat. Zone		Confidence	G. W. Avail.		Confidence	G. W. Qual.	Confidence	Waste	Confidence	G. W. Poll. Potential		Health Hazard		Confidence	Miscellaneous Identifiers		
STEP 1			STEP 2			STEP 3		STEP 4		STEP 5		STEP 6					

APPENDIX 1

TYPICAL SOURCES AND TYPES OF DATA USEFUL IN APPLYING THE ASSESSMENT SYSTEM

Type of Data	Typical Sources	Useful in determining Steps			
		1	2&3	4	6
Property survey	County Records, property owner	*		X	
Well drillers logs	Well Driller, property owner, state records	*	*		X
Water level measurements	Well owners' observations, well drillers' logs, topographic maps, ground water maps (reports)	*	X		*
Topographic Maps	U.S. Geological Survey and designated state sales offices	X			*
Air Photos	U.S. Dept of Agriculture, U.S. Forest Service, etc.				*
County Road Maps	State agencies				*
Ground Water Reports	U.S. Geological Survey, State agencies	*	*		X
Soil Surveys of Counties	U.S. Department of Agriculture	*	X		X
Geologic Maps	U.S. Geological and State Surveys	X	X		X
Waste Character	Owner/operator, State or Federal permits, SIC Code			X	

* - Source of data may be especially useful

X - Source of data may be of slight use or may be used indirectly

APPENDIX 2

MEASURING UNIT CONVERSION TABLE

inch (in)	x	2.54	=	centimeter (cm)
centimeter	x	0.3937	=	inch
feet (ft)	x	0.3048	=	meter (m)
meter	x	3.2808	=	feet
mile (mi)	x	1.609	=	kilometer (km)
kilometer	x	0.621	=	mile
U.S. gallon (gal)	x	0.0038	=	cubic meter (m^3)
cubic meter	x	264.17	=	U.S. gallon
cubic feet (ft^3)	x	0.0283	=	cubic meter
cubic meter	x	35.314	=	cubic feet
acre-foot (ac-ft)	x	123.53	=	cubic meter
cubic meter	x	0.0008	=	acre-feet
hectare	x	10,000.0	=	square meter (m^2)
square meter	x	0.0001	=	hectare
hectare	x	2.471	=	acre
acre	x	0.4047	=	hectare

Hydraulic Conductivity

gpd/ft^2	x	4.72×10^{-5}	=	cm/sec
cm/sec	x	21.2×10^{3}	=	gpd/ft^2
Darcy	x	18.2	=	gpd/ft^2
Darcy	x	8.58×10^{-4}	=	cm/sec

APPENDIX 3

GLOSSARY

Aquifer - a formation, group of formations or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Artesian ground water - synonymous with confined ground water which is a body of ground water overlain by material sufficiently impervious to sever free hydraulic connection with overlying ground water. Confined ground water is under pressure great enough to cause water in a well tapping that aquifer to rise above the top of the confined aquifer.

Discharge area - geographic region in which ground water discharges into surface water such as at springs and seeps and subsurface seepage into streams, lakes and oceans (referred to as base flow in streams).

Karst topography - geologic region typified by the effects of solution of rocks by water. Rock types most likely effected are limestone dolostone, gypsum and salt beds. Features produced are caverns, collapse features on the surface (sink holes), underground rivers and zones of lost circulation for well drillers.

Perched water table - unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a "perched water table" and is sustained by a "perching bed" whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure.

Plume of contaminated ground water - as contaminants seep or leach into the subsurface and enter the ground water, the flow of the ground water past the site of contamination causes the contaminated ground water to move down gradient. This action results in the creation of a "plume" shaped body of ground water containing varying concentrations of the contaminant, extending down gradient from place of entry. The shape of the plume of contaminated ground water is affected by attenuation of the specific contaminants and, to a lesser extent, by dispersion.

Primary permeability - permeability due to openings or voids existing when the rock was formed, i. e. , intergranular interstices.

Recharge area - geographic region in which surface waters infiltrate into the ground, percolate to the water table and replenish the ground water. Recharge areas may be well defined regions such as limestone outcrops or poorly defined broad regions.

Saturated Zone - the zone in the subsurface in which all the interstices are filled with water.

Secondary permeability - permeability due to openings in rocks formed after the formation of the rock, i. e. , joints, fractures, faults, solution channels and caverns.

Unsaturated zone - formerly the "zone of aeration" or "vadose zone". It is the zone between the land surface and the water table, including the "capillary fringe".

Water table - that surface in an unconfined ground-water body at which the pressure is atmospheric. Below the water table is the saturated zone and above is the unsaturated zone.

APPENDIX 4

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16. ABSTRACT

This manual was specifically prepared for implementing a standardized evaluation system for the EPA Office of Drinking Water Surface Impoundment Assessment. The manual describes a first round evaluation system for rating the ground water contamination potential of surface impoundments. The evaluation system contains eight steps:

1. Rating the unsaturated zone
2. Rating the ground water availability
3. Rating the ground water quality
4. Rating the waste hazard potential
5. Computing the overall ground water contamination potential
6. Rating the potential endangerment to current users of the ground water
7. Rating the investigator's confidence in the data
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